University of Alberta

Air Sampling of Volatile Organic Compounds in a Community Near an Industrial Corridor

by

Christine Anne Byrne ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Environmental Science

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University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Air Sampling of Volatile Organic Compounds in a Community Near an Industrial Corridor** in partial fulfillment of the requirements for the degree of **Master of Science** in **Environmental Science.**

Dr. Warren Kindzierski

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Dr. Dan Smith

Dr. Ken Froese

January 28, 2000

Abstract

The community of Sherwood Park, Alberta is located beside a large industrialized area. This study undertook air sampling for selected volatile organic compounds (VOCs) emitted from industrial activities and common indoor sources at homes in Sherwood Park.

The research hypothesis tested was that the proximity of Sherwood Park residences to industrial emissions of VOCs does not significantly increase the concentrations of VOCs indoor and outdoors where humans may be exposed. Samples were collected using passive air monitors, at homes in Sherwood Park and St. Albert (control community) and compared to determine if a statistically significant difference exists.

Wilcoxon rank sum testing of the monitoring results indicate that Sherwood Park does not have higher average VOC concentrations than St. Albert at the 95% confidence level. Results of the study suggest that industrial emissions do not have a measurable impact on air quality at indoor and outdoor receptor locations more typical of human exposure to VOCs.

Acknowledgements

This study would not have been made possible without the generous support of the Capital Health Authority, County of Strathcona, City of St. Albert, and Friends of the Environment. County of Strathcona and City of St. Albert staff members provided important demographic information and maps.

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List of Symbols and Abbreviations

AOSCEHEAP	Alberta Oil Sands Community Exposure and Health Effects Assessment Program
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BDL	Below Detection Limit
CO_2	Carbon Dioxide
CPS	Corporate Planning Secretariat
DE	Desporption Efficiency
ED&T	Economic Development and Tourism
GC	Gas Chromatography
GC/MS	Gas Chromatography/ Mass Spectrometry
HVAC	Heating, Ventilation and Air Conditioning
I/O	Indoor to Outdoor Ratio
IP	Industrial Proximity
MDLs	Method Detection Limits
MS	Mass Spectrometry
NAS	National Academy of Sciences
NO_x	Nitrogen Oxides
O_3	Ozone
QA/QC	Quality Assurance/Quality Control
r_i	Intraclass Correlation Coefficient
SO_2	Sulphur Dioxide
TEAM	Total Exposure Assessment Methodology
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds

Chapter 1: Introduction

1.1 Background

The community of Sherwood Park, Alberta is located near a large industrial corridor that emits various air pollutants. Consequently, Sherwood Park residents have raised concerns regarding the quality of the air in their community. Industries such as oil refineries, smelters and chemical manufacturing plants can all be found in the industrial corridor and they emit a variety of volatile organic compounds (VOCs). Residents of Sherwood Park feel they are being adversely affected by the industrial emissions. The ambient air quality of Sherwood Park is continuously monitored; however uncertainty exists as to how representative ambient measurements are to human exposure. A study done in California found that a central monitoring location could not be used to predict backyard levels of VOCs and the backyard concentrations could not be used to predict the corresponding indoor concentration (Michael et al., 1990).

The main objectives of this study were too:

1) develop a suitable monitoring program in order to facilitate comparisons of VOC levels at the study location (Sherwood Park) relative to a control community (St. Albert);
2) examine levels of VOCs indoors and out at both locations to determine if humans are being exposed to higher levels of VOCs outdoors or within their own homes;
3) determine if levels of VOCs are higher at the study area or are similar to the control community.

1.2 Description of Study Area

The Strathcona industrial corridor is a source of industrial emissions emanating from hydrocarbon storage tanks, oil refineries, smelters, and chemical and shingle manufacturing plants. The community of Sherwood Park is immediately adjacent to the industrial corridor. St. Albert is located ~20km Northwest of the corridor. Figure 1.1 shows the relative location of these two communities and their respective population based on 1996 census information. St. Albert was chosen as the control community because of its location relative to Sherwood Park and because it is similar in size and demographics to Sherwood Park. The purpose of sampling in St. Albert was to gather data to represent urban background levels. A pristine rural environment was not chosen as the control community because it was important to compare Sherwood Park to another urban centre so that if a difference was detected it would not be attributed to background influences of urban activities.

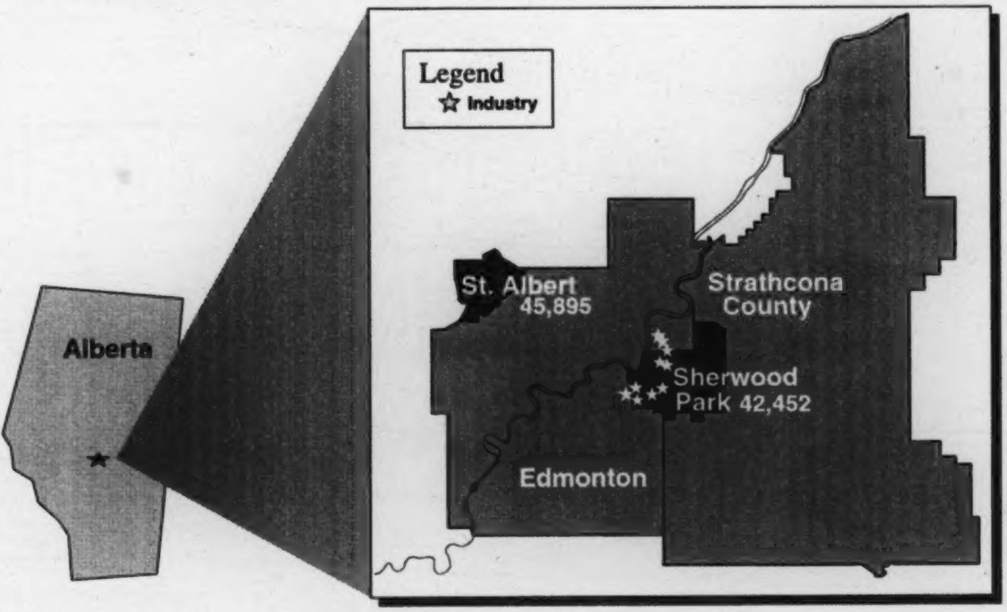

Figure 1.1 Study area.

Of particular interest to this study was that both communities have similar distributions of dwelling types (Table 1.1) (ED&T, 1999; CPS, 1999). This is significant because it is air quality in the homes (dwellings) that is being sampled. Sherwood Park and St. Albert also have similar demographic compositions (ED&T, 1999; CPS, 1995). Figure 1.2 depicts the distribution of age groups for both communities.

Table 1.1 Occupied dwelling units by type (ED&T, 1999; CPS, 1999).

Dwelling Type	St. Albert	Sherwood Park
	(1998 Census)	(1998 Census)
Single Family	76%	87%
Duplex/Fourplex	3%	4%
Townhouse	12%	6%
Apartment	9%	3%

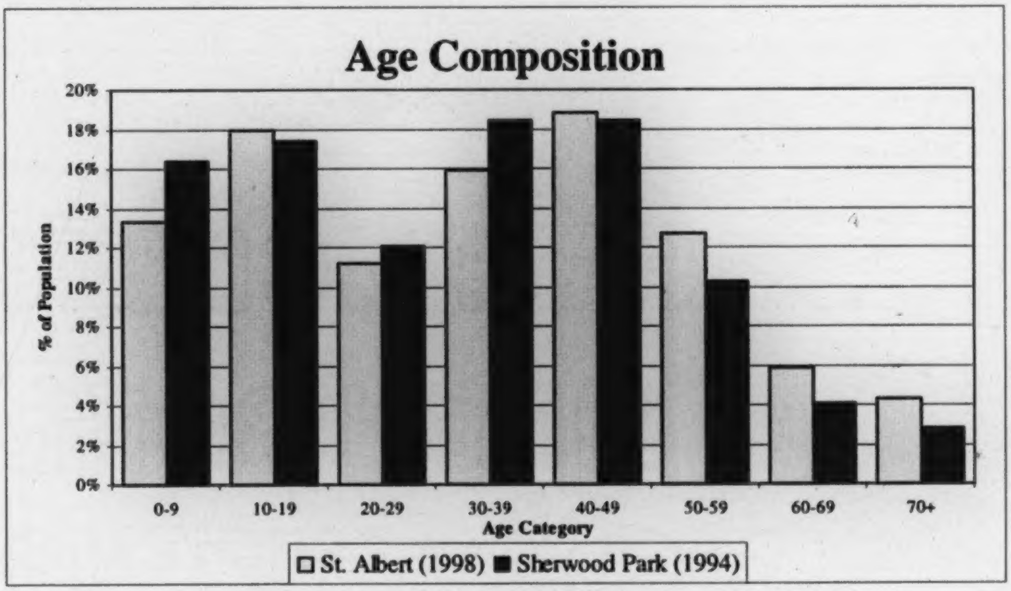

Figure 1.2 Age composition for study areas.

1.3 Hypothesis

The hypothesis tested in this study is that the close proximity of Sherwood Park residences to industrial emissions of volatile organic compounds from the Strathcona industrial corridor does not significantly increase the concentrations of VOCs at receptor locations inside and outside of homes. The rationale for testing this hypothesis is that the background influence of urban activities provide sources and activities yielding VOCs that occur much closer to the home microenvironment than industrial sources and activities releasing VOCs.

1.4 Volatile Organic Compounds

Volatile organic compounds (VOCs) were defined empirically by Wang et al. (1996) as:

1) having low molecular weight, small specific gravity, low water solubility and a low boiling point;
2) including chemical classes such as aliphatic and aromatic hydrocarbons, halocarbons, aldehydes, keytones, and alcohols; and
3) being typically analysed using purge-and-trap gas chromatography coupled with mass spectrometry.

Hines et al. (1993) define VOCs as compounds with vapour pressures greater than 1mm Hg at room temperature and that are present in the air as a vapour.

VOCs have been associated with human health problems and are a precursor of ground level ozone, which is also a health concern and a component of photochemical smog. The main reason VOCs are a problem is their high mobility. Once a VOC has been released, it can be transported over large distances from its source location. This type of transport is a concern because it can lead to population-wide exposures (Cohen, 1996).

1.4.1 Sources of VOCs

Volatile organic compounds have a variety of sources. Sources can be found indoors and out. Outdoor VOC sources can be emitted directly or by fugitive emissions. The outdoor sources include combustion of fuels; fugitive emissions from petrochemical, chemical facilities and utilities; as well as mobile sources, and product use and disposal

(Cohen, 1996). Indoor sources are numerous. VOCs can be released when cooking, cleaning, using office machines, and smoking. Building materials and various consumer products also emit VOCs. Vehicle emissions have been found to impact indoor VOC levels in homes that have attached garages. Indoor sources can be typified as intermittent or long-term off gassing. Intermittent sources include products like cleaning agents that use organic solvents as their active ingredients or as a propellant (Cohen, 1996). Wall panelling, new carpet and coolant system leaks will result in long term off gassing (Cohen, 1996).

1.5 Research Overview

Traditionally, determination of health risks posed by industrial emissions emphasize source-based characterisation (i.e. evaluate dispersion and exposure to receptors based upon what is released from industrial sources). Exposure is largely presumed in these situations without supporting evidence. The opportunity exists to improve our understanding of the health risks by using a receptor-based characterisation method (by evaluating exposure based upon what is measured in environments where the receptor lives). Dissemination of the findings can provide a better understanding of health risks posed to humans by industrial emissions and provide improved knowledge upon which to make environmentally sustainable management decisions for maintaining industrial operations.

This study set out to examine if nearby industrial emissions result in higher concentrations of VOCs in homes of residents of Sherwood Park compared to a community not adjacent to an industrial corridor. In order to accomplish this, a probability sampling method was adopted that would facilitate the collection of indoor and outdoor samples of volatile organic compounds. Samples were collected in and around the homes of volunteers in St. Albert and Sherwood Park. To avoid bias of the homes sampled, a random selection procedure was used to determine which homes would be sampled. Volunteers were recruited through a door-to-door campaign. Prior to beginning the recruitment process, supporting reference material needed to be developed. To aid in recruitment of volunteers, a brochure about the study, a letter of support from the University of Alberta and the Capital Health Authority (principal study sponsors), an information sheet and a participant consent form were all developed (Appendices 8.1 to 8.4). Questionnaires, to be completed by the participants, were also developed to help understand sources that may interfere with the interpretation of the results (Appendix 8.5). Once all the volunteers were obtained, the sampling process began.

1.5.1 Phase I & II Sampling Periods

Sampling involved two phases. Phase I was the fall sampling period and Phase II was the winter sampling period. The fall and winter were chosen for sampling because they were perceived to be the periods of poorest indoor air quality. The decrease in the quality of indoor air was thought to be associated with a decrease in ventilation within homes due to windows being kept closed. The sampling procedures were the same for Phases I and II.

Sampling began by arriving at a volunteer's home at a predetermined time and deploying two passive samplers, one inside the home and the other outside. Twenty-four hours later the samplers were retrieved, Part I of the questionnaire was collected at that time, and Part II of the questionnaire was administered by a field interviewer. After the sampler was retrieved, it was stored on ice until taken back to the lab and placed in a refrigerator. Within one week of sampling, the contaminants collected by the sampler were extracted with carbon disulphide and placed in a deep freeze to await GC/MS analysis.

Chapter 2: Literature Review

2.1 Air Pollution

Pollution has been broadly defined as "an undesirable change in the physical, chemical, or biological characteristics of the air, water, or land that can harmfully affect the health, survival, or activities of humans or other living organisms" (Henry and Heinke, 1996). This definition is significantly broad so that it is not restricted to only the ambient environment or anthropogenic emissions. Pollution has also been defined to include the damage of property as an effect. Air pollution is an important component of pollution due to the ability of contaminants present in the air to be transported over large distances.

Air pollution is caused by the presence of one or more contaminants, gases or particulates, that are of significant concentrations and residence times (Canter, 1996). Sources of air pollutants can be classified as natural or man-made. Natural sources of air pollution include plant pollens, windblown dust, volcanic eruptions and lightning-generated forest fires (Canter, 1996). Once a pollutant has been released, depending on its characteristics, it can have numerous effects. Air pollution can affect human and animal health; cause damage to property; affect plant growth; and cause aesthetic problems. Examples of aesthetic problems are odour, visibility, and discoloration of the air (Canter, 1996).

When examining air pollution for human exposure, it is important to consider the various microenvironments in which humans live. Humans can be exposed to air pollutants in the ambient environment as well as the indoor environment. Exposure does not stop once inside.

2.1.1 Indoor Air Pollution

Ambient air quality data has been the traditional means for assessing population exposure to air pollution. However, over the past decade it has become apparent that a person's greatest exposure occurs while they are inside. Brooks and Davis (1992) define indoor air quality in relation to "how well indoor air satisfies three basic requirements of human occupancy: 1) thermal acceptability; 2) maintenance of normal concentrations of respiratory gases; and 3) dilution and removal of contaminants and pollutants to levels below health or odour discomfort thresholds."

Indoor air pollution can be traced to two sources: interior air and exterior (outdoor) air (Brooks and Davis, 1992). Outdoor air contaminants have a variety of sources, such as industrial emissions, automobiles, and agriculture. These contaminants can be found in homes at levels dependent on their concentration in the ambient environment, rate of infiltration, efficiency of a homes ventilation system and the reactivity of the pollutants (Brooks and Davis, 1992).

The quality of interior air is also a product of indoor pollution. Contaminants can be released to the indoor environment from sources such as building materials, furnishings, appliances, office equipment, human activities, combustion emissions and bioaerosols (Brooks and Davis, 1992).

Physical factors also play a role in indoor air quality. Temperature, humidity, artificial lighting, and vibration and noise can all influence the perception of indoor air quality. Temperatures ranging from 20 to 26°C are believed to be an acceptable comfort range, with the lower portion being recommended. An increase of VOC off gassing from indoor materials may result from temperatures beyond this range (Brooks and Davis, 1992). The extremes of humidity also have problems associated with them. A relative humidity greater than 70% can result in microbial growth and contamination, and a relative humidity less than 20% may cause drying of mucous membranes or skin for certain individuals (Brooks and Davis, 1992). Artificial lighting can cause problems that are similar to those associated with poor indoor air quality. For example, low or high levels of lighting, inadequate contrast, and excessive glare can cause eye irritation and headache. Similarly, vibrations and noise can cause dizziness and irritability, which are often attributed to indoor air pollution (Brooks and Davis, 1992).

2.2 Exposure Assessment

Central to the justification of this study is the need for an improved understanding of whether a person's microenvironment air quality (and consequently their exposure) is affected as a result of residing in close proximity to industrial emissions. The American National Academy of Sciences (NAS) (1991) states that "exposure assessment provides fundamental information for describing the distribution (including high and low extremes) of contaminant exposures within a population, for estimating the doses received from different media, and for determining routes of entry into the body." This study attempts to provide information on the distribution of contaminants within two populations (theoretically one affected and one unaffected community residing in close proximity to and away from industrial emissions, respectively).

To manage risk effectively, exposure assessments are a necessity. Exposure assessments help determine (NAS, 1991):

- concentration distributions in time and space for different environmental media;
- population or subgroups at high and low risk;
- efficient, effective and representative environmental monitoring programs;
- chemical and physical contributions of various sources to concentration;
- factors that control contaminant release into environmental media, routes of environmental transport, and routes of entry into humans;
- effective mitigation measures; and
- compliance through mitigation measures to achieve health standards.

2.2.1 Definition of Exposure

Several definitions of exposure have been put forward. Ott (1982) described exposure as the joint occurrence of two events: 1) a contaminant of concentration C is present at a particular location in space at a particular time, and 2) a person is present at the same time and location in space. This definition was further expanded to include a consideration for the point of contact. The adjustment was made to account for the fact that different parts of a target may be receiving different exposures at the same time because the concentrations at various points may vary (Ott, 1995). The result defines exposure as the joint occurrence of 1) concentration C present at a specific location at time t, and 2) point i of the target is present at the same location and time t. The second definition allows for the application to a number of objects (i.e. humans, fish, and plants) and any carrier medium.

A narrower definition of exposure was given by the National Academy of Sciences in 1991: "an event that occurs when there is contact at a boundary between a human and the environment with a contaminant of a specific concentration for an interval of time: the units are concentration multiplied by time" (NAS, 1991).

2.2.2 Measurement of Exposure

Exposure to environmental contaminants can be measured in a number of ways. Figure 2.1 is a schematic of potential exposure assessment methods. Two general approaches used are direct and indirect measurement. The direct approach measures exposure by personal monitoring or biological markers. Personal monitoring involves measuring the concentration of pollutants in the air breathed, water drunk and the food eaten (Ott, 1985). Biological markers are cellular, biochemical, or molecular measures, indicative of pollutants, obtained from media such as human tissues, cells, or fluids (NAS, 1991).

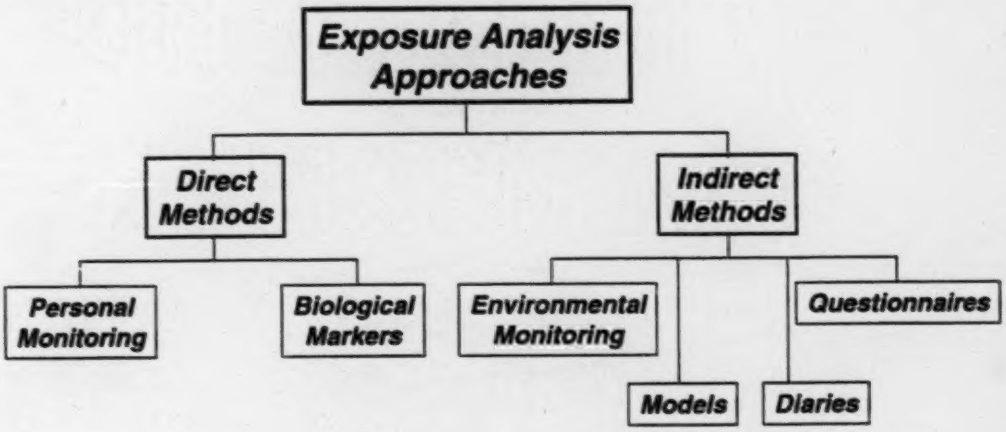
Exposure Analysis Approaches
Direct Methods
Indirect Methods
Personal Monitoring
Biological Markers
Environmental Monitoring
Questionnaires
Models
Diaries

Figure 2.1 Approaches for measurement of exposure (Adapted from NAS, 1991).

The second general approach, indirect, constructs an exposure profile by combining time activity information with the expected concentrations of contaminants in a particular location (Ott, 1985). The necessary information is obtained by using a combination of questionnaires, models, diaries and environmental monitoring.

Questionnaires and diaries are used to determine 1) physical properties of the microenvironment, 2) potential sources, and 3) activity patterns of individuals. Models are used to estimate the exposures when direct measurement is not possible or impractical (NAS, 1991). Environmental monitoring involves taking measurements of pollutant concentrations in microenvironments, where the exposure is taking place. A microenvironment is defined as a location in time and space in which a pollutant concentration is assumed to be uniform (Duan, 1982).

2.2.3 Importance of Indoor Environment to Exposure

The visual impact of seeing pollution generated by industry and automobiles has led people to believe outdoor air pollution is more important than indoor pollution (Hines et al., 1993). As a result, resources have been spent on studying and reducing industrial and automotive emissions, while indoor air pollution has been neglected.

When energy costs began to rise, construction of buildings focused on energy conservation. New construction strategies resulted in more energy efficient buildings. These buildings reduce the infiltration of fresh air, to the point where 80% to 90% of the air is re-circulated to reduce energy costs (Hines et al., 1993). This re-circulation of air causes problems because of the large number of indoor sources of pollution. Pollutants with indoor sources can build-up over time. Several studies have found indoor levels of organic pollutants greatly exceed outdoor levels (Wallace et al., 1986; Cohen et al., 1989; and Hartwell et al., 1992). The indoor environment is important because 80% to 90% of a person's time is usually spent indoors, between their home, workplace, shops and supermarkets (Hines et al., 1993).

Binder et al. (1976) found outdoor air measurements did not accurately reflect the air pollution load experienced by individuals living in their sampling area. Their study focused on children, who spent between 60% and 80% of their time indoors on an average school day. Fugas et al. (1988) concluded that indoor concentrations at home might serve as a fair approximation of personal exposure. The people in their study were found to spend between 65% to 68% of their time at home.

2.2.4 Exposure to VOCs

Exposure to VOCs can occur through inhalation, ingestion or dermal exposure. Figure 2.2 provides a diagram of possible routes of exposure to VOCs. A receptor may be exposed by inhaling polluted air or drinking contaminated water, or they could be exposed by such things as eating the beef of cattle that were exposed by inhalation, drinking water or contaminated feed (Cohen, 1996). Of the exposure pathways, inhalation is the major contributor to an individual's lifetime risk, followed by drinking water. However, under certain circumstances exposure can occur when vegetables have been grown at a contaminated site or when domesticated animals have been raised on a contaminated site (Cohen, 1996).

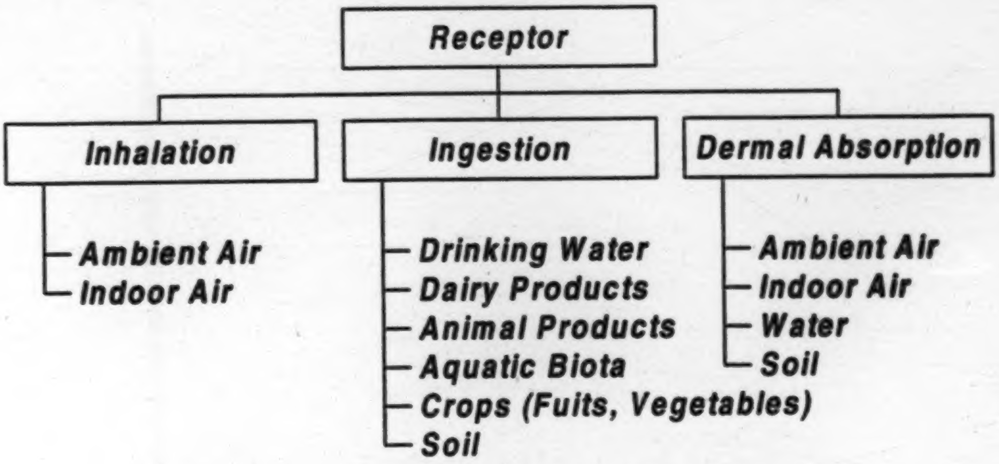
Receptor
Inhalation
Ingestion
Dermal Absorption
Ambient Air
Indoor Air
Drinking Water
Dairy Products
Animal Products
Aquatic Biota
Crops (Fuits, Vegetables)
Soil
Ambient Air
Indoor Air
Water
Soil

Figure 2.2 **Exposure pathways (after Cohen, 1996).**

2.2.5 Health Issues

Public and regulatory authorities have raised concern over low levels of VOCs indoors causing acute and chronic human health effects (Brooks and Davis, 1992). Whether a health effect will result from exposure to a VOC depends upon 1) toxicity; 2) route of exposure; 3) actual dose received; 4) individual susceptibility; and 5) ability of the VOC to react with other chemicals (Brooks and Davis, 1992).

VOCs with the highest probability of being removed by the upper respiratory tract are generally more reactive and water-soluble. The less reactive and water-soluble the VOC, the further it will travel down the respiratory system. Considerable time has been spent researching the effects of exposure to a single VOC. However, more often individuals are exposed to several VOCs at once, under low concentrations. Depending on multiple physiological and psychological factors the extent of a health impact can vary due to the complexity of the interactions. Strategies to prevent and remediate indoor air quality problems involve choosing low VOC emission materials, supplies and equipment; assuring appropriate ventilation; and using common sense (Brooks and Davis, 1992).

Due to the large number of compounds that can be detected in the indoor environment it is difficult to associate health and comfort problems with specific compounds (Sterling, 1985). VOCs as a group are often associated with Sick Building Syndrome, the symptoms of which include: irritation of eye, nose and throat; dry mucous membranes and skin; erythema, mental fatigue and headache; airway infections and cough; hoarseness and wheezing; unspecific hypersensitivity reactions; nausea; and dizziness (Molhave, 1985). Aldehydes, alcohols, and aromatics have been found to be eye and upper respiratory irritants. However, at low concentrations the severity of the symptoms depends on the sensitivity of the exposed individual (Sterling, 1985).

Sterling (1985) has identified several important considerations when assessing health effects due to exposure to VOCs and other indoor pollutants:

- exposures may be additive or synergistic;
- health effects resulting from chronic exposure versus acute exposures at low concentrations are not known;
- populations vary in age, sex, susceptibility and life style;
- odours can lead to complaints and serve as stressors;
- exposure to VOCs may increase susceptibility to effects from other compounds (vice versa) as well as aggravate pre-existing conditions; and
- individuals may become sensitized/allergic to compounds over time.

Molhave et al. (1986) examined the effects of exposing individuals to a mixture of 22 VOCs for 2.75 hours. The mixture was made up of common indoor air pollutants and the participants were exposed to concentrations of 0, 5 and 25 mg/m^3. Significant correlations were observed between exposures at 5 and 25 mg/m^3 and irritation of the eyes, nose and throat. Subjects reacted to the introduction of the pollutants within 30 minutes and showed no signs of adaptation (Molhave et al., 1986).

2.2.5.1 Risks Associated with Exposure to VOCs

Upper-bound lifetime risks of cancer were estimated for a select group of VOCs based on results of TEAM studies performed in the United States between 1980 and 1987 (Wallace, 1991). The risks were calculated by multiplying exposure and upper-bound potency. Exposure was based on measurements from the TEAM studies. Cancer potencies were obtained from the EPA and are upper-bound potencies calculated from animal experiments, with the exception of benzene. The potency for benzene was based on human epidemiological studies from occupational exposures. Uncertainty surrounding risk calculations result from extrapolating from animals to humans and high to low dose. Risk estimates can be off by factors of 10, 100 or more, and at the most the actual cancer risk may in fact be zero (Wallace, 1991).

Upper-bound lifetime cancer risks were calculated for 12 VOCs and the negligible risk level was defined as 10^{-6}. Seven of the twelve compounds were found to have risks greater than 10^{-6} by a factor of 10 or more: benzene, vinylidene chloride, *p*-dichlorobenzene, chloroform, ethylene dibromide, methylene chloride and carbon tetrachloride. Table 2.1 shows calculated risks for all twelve of the compounds. Benzene is considered a human carcinogen as a result of human epidemiological studies of occupational exposure. Sources of benzene exposure inside the home are numerous and include active and passive smoking, attached garages, consumer products (pens, paints, glues, rubber), and storing gasoline and kerosene (Wallace, 1991).

Table 2.1 Upper-bound lifetime cancer risks based on TEAM Studies (Wallace, 1991).

Compound	Exposure $\mu g/m^3$	Potency $(\mu g/m^3)^{-1} \times 10^{-6}$	Risk $X\ 10^{-6}$
Benzene			
Air	15	8	120[a]
Smokers	90	8	720[a]
Vinylidene Chloride	6.5	50	320
Chloroform			
Air	3	23	70
Showers (inhalation)	2	23	50
Water	30 µg/l	2.3 µg/l	70
Food & Beverages	30 µg/l	2.3 µg/l	70
p-Dichlorobenzene	22	4	90
1,2-Dibromoethane	0.05	510	25
Methylene chloride	6	4	24
Carbon tetrachloride	1	15	15
Tetrachloroethylene	15	0.6	9
Trichloroethylene	7	1.3	9
Styrene			
Air	1	0.3	0.3
Smokers	6	0.3	2
1,2-Dichloroethane	0.5	7	4
1,1,1-Trichloroethane	30	0.003	0.1

[a] Based on human epidemiology, therefore mean as opposed to upper-bound estimates

For most of the compounds, indoor sources accounted for the majority (80 to 100%) of the risk associated with air exposure. The USEPA has even gone as far to declare that "indoor air pollution is one of the greatest threats to public health of all environmental problems" (Wallace, 1991).

2.3 *Volatile Organic Compounds (VOCs)*

2.3.1 Sources

VOCs can be emitted from a variety of sources. The main sources of VOCs indoors can be grouped as emissions from combustion, building materials, household products, humans, water and tobacco smoke. Outdoor VOCs result from a variety of human activities and natural processes. Outdoor VOCs can also be a source of indoor pollution and vice versa.

2.3.1.1 Indoor Sources

Several studies have been done to identify possible indoor sources of VOCs. Wallace et al. (1987) performed a study in which they monitored contaminants in buildings to identify chemicals that might be of concern. Upon identification of 17 target compounds they performed tests on building materials and consumer products to identify possible sources and used chamber tests to determine source emission rates. The study found the majority of observed concentrations in monitored buildings could be accounted for by emissions from a few common materials (paints, cleaners, glues and insecticide propellants). These materials were emitting a number of potentially toxic, mutagenic or carcinogenic chemicals in concentrations great enough to result in measured concentrations in the building. Results of their tests led to the conclusion that "common materials found in nearly every home and place of business may cause elevated exposures to toxic chemicals" (Wallace et al., 1987).

Another study examined 1,159 common household products as potential sources of indoor air pollution. Sack et al. (1992) analysed the 1,159 products for 31 VOCs. It was found that 935 products contained at least one or more of the 31 target compounds at concentrations greater than 0.1% by weight. The compounds observed with the greatest frequency were methylene chloride, 1,1,1-trichloroethane, acetone, 2-butanone, ethylbenzene, methylcyclohexane, n-octane, toluene, and xylenes. Five compounds (chlorobenzene, d-limonene, 1,1,2,2-tetrachloroethane, n-nonane and styrene) were not observed in any of the products (Sack et al., 1992).

Aliphatic hydrocarbons such as methane, ethane, propane and hexane result from incomplete combustion and thus can contribute to indoor air pollution. As well, cooking with oil and butter has also been known to contribute to indoor levels of volatile organic compounds (Hines et al., 1993).

Building materials such as adhesives, carpets and paints can all contribute to indoor air pollution. Depending on the chemical composition of an adhesive, it can be a significant source of VOCs (Hines et al., 1993). Moreover, paints and carpets have been found to be predominant sources of organic compounds indoors, which is justifiable as approximately 95% of all interior surfaces are painted or covered with carpet (Hines et al., 1993). The contribution of paint to indoor air pollution also depends upon its formulation. Water-based paints have been found to emit significantly less VOCs than solvent-based paints. Some organic compounds identified in building materials are indicated in Table 2.2.

Household products also contribute to indoor concentrations of VOCs, especially when they originate from an aerosol spray can. Several products still use aerosols, such as air fresheners, antiperspirants, hairsprays, and cleaners. Common aerosol propellants are propane, isobutane, trichlorofluromethane and dichlorodifluromethane (Hines et al., 1993). In addition to propellants, the products themselves contain VOCs. Cleaners and polishers may contain *m*-xylene, acetone, 1,1,1-trichloroethane, n-octane and methylene chloride (Sack et al., 1992). Fabric and leather treatment products have been found to contain chlorinated solvents most frequently (Sack et al., 1992). Pesticides have also been found in homes, but they are generally present in very low concentrations (Hines et al., 1993). VOCs that are found in common household products are listed in Table 2.2.

Humans have also been shown to emit a variety of VOCs. Some examples of VOCs emitted in the breath of humans are acetone, ethyl alcohol, and methyl alcohol (Hines et al. 1993).

Most water distribution systems in urban areas are treated with chlorine. As a result, chlorinated hydrocarbons are being produced in the water as by products. Chloroform, trichloroethylene, carbon tetrachloride, 1,2,3-trichloropropane and tetrachloroethylene have all been found in treated water (Hines et al., 1993). These compounds can be released whenever the water is used. Exposure to VOCs from water can occur by inhalation and direct absorption during showering, bathing or washing dishes (Hines et al., 1993).

Smoking can also be a contributor to indoor air pollution. The greatest source of pollution from tobacco smoke is the sidestream smoke. Volatile gases found in sidestream smoke include aromatic amines, N-nitrosamines, aldehydes, simple aromatics, carboxylic acids and phenols (Otson and Fellin, 1992).

Table 2.2 VOCs found in common indoor materials and products (Hines et al. 1993).

Material/Product	Organic Compounds Identified
Latex caulk	Methyl ethyl ketone, butyl propionate, 2-butoxyethanol, butanol, benzene, toluene
Floor adhesive (water –based)	Nonane, decane, undecane, dimethyloctane, 2-methylnonane, dimethylbenzene
Particleboard	Formaldehyde, acetone, hexanol, propanol, butanone, benzaldehyde, benzene,
Moth crystals	*p*-Dichlorobenzene
Floor wax	Nonane, decane, undecane, dimethyloctane, trimethylcyclohexane, ethylmethylbenzene
Wood stain	Nonane, decane, undecane, methyloctane, dimethylnonane, trimethylbenzene
Latex paint	2-Propanol, butanone, ethylbenzene, propylbenzene, 1,1-oxbisbutane, butylpropionate
Furniture polish	Trimethylpentane, dimethylhexane, trimethylhexane, trimethylheptane, ethylbenzene, limonene
Polyurethane floor finish	Nonane, decane, undecane, butanone, ethylbenzene, dimethylbenzene
Room freshener	Nonane, decane, undecane, ethylheptane, limonene, substituted aromatics (fragrances)
Tape	1,2-Dichloroethane, benzene, carbon tetrachloride, chloroform, ethyl benzene, methyl chloroform, styrene, tetrachloroethylene, trichloroethylene
Cosmetics	Methyl chloroform, styrene, tetrachloroethylene, trichloroethylene
Deodorants	Limonene, styrene
Health and beauty aids	Benzene, limonene, styrene, methyl chloroform, trichloroethylene
Electrical equipment	1,2-Dichloroethane, benzene, carbon tetrachloride, chloroform, ethyl benzene, methyl chloroform, styrene, tetrachloroethylene, trichloroethylene
Ink pen	Benzene, carbon tetrachloride, chloroform, methyl chloroform, styrene, tetrachloroethylene, trichloroethylene
Paper	Benzene, chloroform, methyl chloroform, tetrachloroethylene, trichloroethylene, formaldehyde
Photo equipment	Benzene, carbon tetrachloride, chloroform, ethyl benzene, methyl chloroform, styrene, tetrachloroethylene
Photo film	Benzene, chloroform, ethylbenzene, methyl chloroform, styrene, trichloroethylene

2.3.1.2 Outdoor Sources

Outdoor sources of VOCs stem primarily from human activities; however natural sources do exist. Some anthropogenic sources of VOCs include transportation equipment; stationary source fuel combustion; industrial processing of chemicals and natural gas; organic solvents; and solid waste (Singh and Zimmerman, 1992). Anthropogenic sources of some specific hydrocarbons are listed in Table 2.3. Since the 1970's a decline in VOC emissions has been observed in the United States. This decline has been attributed to improved control strategies such as catalytic converters and better fuel efficiencies (Singh and Zimmerman, 1992). On a global scale, another major source of emission is biomass burning. Smaller sources of VOCs include open burning, incineration and forest fires (Singh and Zimmerman, 1992).

Forest fires can also be either a natural or human related source of VOC emissions, if the result of a prescribed burn or the result of human error. Other natural sources include oceanic and plant emissions. Oceans are a source of light hydrocarbons. Light alkanes and alkenes have been found to be supersaturated in seawater compared to their atmospheric burden (Singh and Zimmerman, 1992). Oceanic emissions are important on a global scale as 70% of the emissions originate in the tropics. Ethylene and propylene are the main emissions, with ethane and propane accounting for the majority of the remainder (Singh and Zimmerman, 1992).

Plants are another source of natural emissions. Isoprene and monoterpenes are the main compounds emitted; however other more complex organic compounds are also emitted (Singh and Zimmerman, 1992). Large uncertainty exists with plant emission estimates, but emissions have been found highest in warmer temperatures and isoprene emissions are strongly effected by the availability of sunlight. Table 2.3 summarises some sources of specific hydrocarbons.

Table 2.3 **Global sources of specific hydrocarbons (adapted from Singh and Zimmerman, 1992).**

Hydrocarbon	Major Sources
Ethane	Natural gas emissions, biomass burning, oceans, grasses and other vegetation
Ethylene	Fuel combustion, biomass burning, oceans, terrestrial ecosystems
Acetylene	Auto emissions, biomass burning
Dimethyl sulphide	Oceanic, terrestrial biogenic emissions
Propane	Natural gas, biomass burning, oceans, grasses and other vegetation
Propylene	Fuel combustion, biomass burning, oceans
n-Butane	Fuel combustion, natural gas, biomass burning, oceans
Isobutane	Fuel combustion, natural gas, biomass burning, oceans
Butenes	Fuel combustion, biomass burning, oceans
n-Pentane	Fuel combustion, natural gas
Isopentane	Fuel combustion, natural gas
Benzene	Fuel combustion, biomass burning
Toluene	Fuel combustion, solvents, biomass burning
Xylenes (*o,m,p*)	Fuel combustion, solvents, biomass burning
Isoprene	Forest/plant emissions
Monterpenes and other biogenics	Forest/plant emissions

2.3.2 Seasonal Trends

Studies have been done to test whether VOC levels are influenced by season. Within the ambient environment, VOC levels can be influenced by reactions with hydroxyl (OH) radicals. The abundance of OH radicals is strongly seasonal (Singh and Zimmerman, 1992). Levels in the ambient air can also be influenced by seasonal variations in the emission of VOCs. For example, emission of isoprene and terpene are at a maximum in the summer and a minimum in the winter. As well, in the United States anthropogenic emissions may be approximately 10% greater in the spring and summer than in the fall and winter (Singh and Zimmerman, 1992). VOC levels can also be influenced by meteorological conditions, such as seasonal changes in mixing patterns. Non-methane hydrocarbons may decline in the summer due to dilution resulting from significant advective and vertical mixing (Singh and Zimmerman, 1992).

Cheng et al. (1997) looked for seasonal variability of selected VOCs in the Edmonton area from 1991 to 1993. VOCs were monitored at a station in the downtown area and at a station located in the industrial corridor east of the city. A strong seasonal pattern was observed at the downtown station. The highest median VOC concentration occurred in the winter, while the minimum occurred during the summer (Cheng et al., 1997). This pattern was not observed at the industrial site. The study concluded that seasonal variation observed at the downtown station could be attributed to variations in meteorological conditions. Lack of a seasonal pattern at the industrial site was attributed to the large number of sources in the area (Cheng et al., 1997).

A survey of homes from across Canada tried to determine if the season influenced the quality of VOCs in indoor air. The study found mean summer concentrations to be lower than other seasons, but no clear trend was observed for spring, fall or winter (Fellin and Otson, 1993). An assumption was made that ventilation in the homes would be greatest in the summer leading to dilution of indoor pollutants. Results supported this assumption but they were not conclusive. During the spring and fall, or when the temperatures were between 0°C and 15°C, average VOC concentrations were greater than summer values and lower than winter levels (Fellin and Otson, 1993). The observed trend was believed to be consistent with increased ventilation; however it was also believed that other influences were probably more important. Winter is expected to have the least ventilation and summer the most. Further analysis of this data set was presented in 1994 when a factor analysis was done to test the significance of seasonal variability. Seasonal influence was tested with indoor VOC concentration, season, outdoor temperature and outdoor relative humidity as the factors. Direct correlation between indoor VOC concentration and seasonal periods and outdoor temperature or relative humidity was found to be small (Fellin and Otson, 1994). Groups of compounds commonly found in household products were found, by factor analysis, to explain more of the observed variability. The study concluded that indoor sources were more likely to influence indoor concentrations of VOCs than climatic factors (Fellin and Otson, 1994).

Total Exposure Assessment Methodology (TEAM) studies conducted in the United States also examined the influence season might have on variability. Ratios of winter to spring or summer median concentrations of specific VOCs (nine in total) were calculated for measurements taken in Los Angeles, California and Bayonne/Elizabeth, New Jersey. Measurements were taken for breath, overnight personal air, daytime personal air, overnight outdoor air and daytime outdoor air. Ratios were calculated for winter to spring measurements in Los Angeles and winter to summer measurements in Bayonne/Elizabeth. The Los Angeles ratios were much greater than one for both personal and outdoor air (Hartwell et al., 1987b). In comparison, this trend was not as well defined for Bayonne/Elizabeth, although the ratios for daytime personal and outdoor air were usually greater than one (Hartwell et al., 1987b).

Seasonal variation was the focus of a study done in Berlin (West). Between April 1986 and April 1987, 12 homes were monitored with passive samplers for 26 two-week periods (Seifert et al., 1989). To examine seasonal variability, total VOC concentration was used as the indicator. The study found total VOC concentrations to be two to three times higher during the cold season (November to April) compared to the warm season (April to October).

2.3.3 Indoor/Outdoor Relationship

The relationship between indoor and outdoor concentrations of various pollutants has been examined. Typical outdoor pollutants (sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and ozone (O_3)) are often found in higher concentrations outdoors compared to indoors, whereas compounds that commonly have indoor sources such as VOCs are found to have higher indoor concentrations than outdoor concentrations. Concentrations of SO_2, NO_2 and O_3 have been found to have lower concentrations indoors than out; because a building's walls, windows and roof acts as a screen (Harrison et al., 1988). The trend toward energy efficient homes has led to much less infiltration and exfiltration of air pollutants, which in turn leads to increases in indoor concentrations of pollutants with indoor sources. Decreases in building ventilation, increased use of synthetic materials and increased use of unvented combustion appliances for space heating have led to a decrease in indoor air quality (Sexton and Wesolowski, 1985).

The USEPA gathered available outdoor and indoor data on air concentrations of VOCs into a single database. The database included 320 VOCs with 261 compounds measured outdoors and 66 measured indoors in both residential and commercial environments (Shah and Singh, 1988). From the database, it became evident that VOCs were typically present in very low concentrations, both indoors and outdoors. Almost 50% of the compounds fell into the 0.01 to 1.0 ppbv concentration range and only 10% and 25% of the compounds had median concentrations exceeding 1 ppbv for outdoor and indoor air, respectively (Shah and Singh, 1988). For compounds that were in the upper quartile (chloroform, 1,1,1-trihloroethane and tetrachloroethene), concentrations were found to be higher indoors than out (Shah and Singh, 1988).

Pellizzari et al. (1986) analysed matched indoor and outdoor air samples collected during the TEAM studies. The samples were collected overnight, in five geographical areas of the United States. For the majority of compounds studied, the indoor median and maximum values were higher than matched outdoor concentrations. Based on the results, researchers concluded that the quality of air indoors was poorer than outside for the compounds identified. This was an important finding because all of the areas studied were selected to represent high urban-industrialised situations (Pellizzari et al., 1986).

A study was done in the Kanawha Valley of West Virginia to investigate the relationship between indoor and outdoor air for a heavily industrialised area. This area of West Virginia is known for its chemical manufacturing industry. Despite being heavily industrialised the study found VOC concentrations to be higher indoors compared to outdoors. Many of the measurements taken outside were below detection limits. The researchers concluded that presence of indoor sources of VOCs were more important than outdoor sources (Cohen et al., 1989).

A study of indoor/outdoor levels of VOCs was also done in Munich, Germany. VOC measurements were taken simultaneously with indoor measurements of oxides of nitrogen (NO_x) as an indicator of air infiltration. All VOC measurements were higher indoors except in a few cases concentrations of benzene were higher outdoors (Gebefuegi et al., 1995). Only a weak correlation between indoor NO_x and indoor aromatics was observed. However, a good correlation was observed between indoor NO_x and outdoor xylenes and ethylbenzene. This is believed to be a result of simultaneous generation of outdoor NO_x and outdoor aromatics. The researchers generally found that possible sources of aromatics may be infiltration of polluted outdoor air. However, since indoor concentrations of VOCs were continually greater than outdoor concentrations, their explanation lies with indoor sources or accumulation of infiltrated compounds. With sufficient ventilation, indoor concentrations of VOCs cannot be lower than outdoor levels, resulting in interdependence between the quality of the air indoors and out (Gebefuegi et al., 1995).

Another study on indoor and outdoor concentrations of VOCs was done in Seoul and Taegu, Korea. A trend of higher indoor concentrations relative to outdoor concentrations was observed, but the results were not statistically significant at the 0.05 confidence level. This led to the conclusion that for the compounds monitored in these two cities, the major VOC sources are outdoors (Baek et al., 1997). The major source of VOCs monitored is believed to be motor vehicles. Strong correlations were observed between the indoor and outdoor measurements of vehicle related pollutants (Baek et al., 1997). For the non-smoking homes, the indoor to outdoor ratios were close to one. However, in smoking homes the ratios were significantly greater than one for certain compounds. This suggests that the main factor influencing indoor air quality in these cities is outdoor air, except in smoking homes where there is an additional indoor source (Baek et al., 1997).

2.4 *Review of Designs and Findings of VOC Studies*

In the past decade, research efforts have increased into the occurrence of volatile organic compounds in homes. Several studies have examined the level of VOCs that people are encountering within their own homes. A recent study by Health and Welfare

Canada examined VOC levels inside and outside of Canadian homes (Fellin and Otson, 1993). Earlier studies initiated by the U.S. Environmental Protection Agency (USEPA) examined VOCs in personal air, indoor and outdoor air, exhaled breath and drinking water. These studies are collectively known as the Total Exposure Assessment Methodology (TEAM) study. Numerous other studies have been conducted elsewhere on smaller scales. The designs and methods applied in these studies were used to help formulate a design for the study conducted in Sherwood Park and St. Albert.

2.4.1 TEAM Study

The Total Exposure Assessment Methodology (TEAM) Study was set up to develop and assess a methodology suitable for measuring human exposure and body burden to toxic substances. Based on the study design the goal was to obtain population estimates of exposure and body burden (Hartwell et al., 1992). The study was carried out throughout the United States and involved environmental and human sampling of VOCs. The TEAM Study involved three phases. The first phase was a field test of the methodology and it was carried out in New Jersey and North Carolina. The second phase sampled people in New Jersey, North Carolina and North Dakota. The objective of the second phase was to estimate exposures for a population exposed to industrial contaminants and to compare it with exposures in a non-industrial area. Bayonne and Elizabeth, New Jersey were chosen to represent an industrial/chemical manufacturing area. In contrast, Greensboro, North Carolina and Devils Lake, North Dakota were chosen for their lack of chemical manufacturing. The third phase was an application of the methodology developed in the second phase; it was applied to a population in

California (Wallace et al., 1988). The results of selected compounds from Phase II and III are summarised in Table 2.4 and Table 2.5.

Table 2.4 **Median personal air concentrations from Phase II and III of TEAM study (µg/m^3) (Hartwell et al., 1987b).**

	New Jersey		California		Greensboro		Devils Lake	
	Night	Day	Night	Day	Night	Day	Night	Day
Ethylbenzene	5.0	5.5	4.2	6.0	2.2	3.1	2.7	2.8
o-Xylene	5.5	6.2	5.4	7.4	3.7	3.8	3.5	2.8
(*m+p*) Xylene	13	15.	14.	19	6.4	7.6	8.4	7.0
Benzene	10	8.9	8.5	11	11	6.9	---	---
Tetrachloroethylene	5.9	7.1	4.6	5.1	2.8	2.6	4.4	5.3
1,1,1-Trichlorethane	12	9.1	12.	17.	26	32	37	17
m,p-Dichlorobenzene	3.3	2.8	1.4	1.5	3.4	2.3	1.7	2.8
Styrene	1.6	1.5	1.5	1.7	0.9	0.7	---	---
Chloroform	2.1	1.5	1.0	0.6	2.3	0.9	0.1	0.2
Sample Size	199-205	189-193	234-235	227-233	24	24	23	24

Table 2.5 **Median outdoor air concentrations from Phase II and III of TEAM study (µg/m^3) (Hartwell et al., 1987b).**

	New Jersey		California		Greensboro		Devils Lake	
	Night	Day	Night	Day	Night	Day	Night	Day
Ethylbenzene	2.9	2.0	3.3	3.0	0.3	0.7	0.03	0.05
o-Xylene	3.3	1.9	4.1	3.5	0.6	1.3	0.05	0.5
(*m+p*) Xylene	9.1	6.0	11	9.7	1.5	2.9	0.05	0.07
Benzene	7.9	4.5	4.2	4.8	0.4	12	---	---
Tetrachloroethylene	1.8	3.3	2.2	2.4	0.7	0.5	0.7	1.3
1,1,1-Trichlorethane	4.7	4.1	6.6	5.9	60	76	0.05	0.07
m,p-Dichlorobenzene	1.1	0.7	1.0	0.5	0.4	0.4	0.07	0.1
Styrene	0.4	0.3	1.0	0.7	0.1	0.1	---	---
Chloroform	0.1	0.1	0.4	0.2	0.1	0.05	0.05	0.07
Sample Size	57-80	55-76	57-58	57-59	6	6	5	3-4

2.4.1.1 Phase II

The study design developed for Phase II of the TEAM Study was a stratified three-stage design. The first stage stratified Bayonne and Elizabeth into geographic areas based on proximity to major point sources of pollution and socio-economic status. From this, 110 geographical areas were selected with probability proportional to size. The main purpose of the first stratification was to control the distribution of samples in relation to variables that may affect exposure. During the second stage the number of dwelling units in each area were counted. If the count was 51 or less the entire area was selected, otherwise, a cluster of 51 homes was selected. The 51 homes within each area were then screened for age, sex, smoking status and occupation. The third stage used the screening data to select a stratified sample of individuals for personal exposure monitoring (Wallace et al., 1986). Three questionnaires were used in the course of the Study: 1) Household Screening Questionnaire; 2) Household Characteristics Questionnaire and 3) 24-hour activity recall questionnaire. The first questionnaire was used in the second stage and the second questionnaire was used in the third stage. The Household Screening Questionnaire collected information on address, occupation and smoking status for stratifying the second sampling stage. The second questionnaire, Household Characteristics, was used to identify characteristics of the participants such as indoor-outdoor time budgets, hobbies, physical condition, diet, heating/ventilation and sources of drinking water. The third questionnaire was used for the personal exposure monitoring study and identified potential exposures such as smokers, cleaning agents, chemical mixtures, and auto/bus trips (Wallace et al., 1986).

Samples were taken in personal air, outdoor air, breath and water. Air samples were collected using active samplers. Electron impact mass spectrometry was used to characterise and quantify the samples. During analysis of the data, non-detects were assigned a value of half the limit of detection and trace quantities were assigned a value half way between the limit of detection and the quantifiable limit (Wallace, et al. 1986).

Three classes of compounds were identified during the analysis: 1) ubiquitous compounds (present in 60 to 98% of air and breath samples); 2) compounds often but not always present; and 3) compounds occasionally found (< 10% detected in most sample types) (Wallace et al., 1986). The first class included the solvents 1,1,1-trichloroethane and tetrachloroethylene as well as four aromatic compounds common to gasoline and paint: benzene, two xylene isomers and ethylbenzene. The second class contained two other solvents, carbon tetrachloride and trichloroethylene. Three other compounds were also identified for this class, chloroform, styrene and *p*-dichlorobenzene. Chloroform is typically released by chlorinated water during hot showers. Styrene and *p*-dichlorobenzene are common consumer products. The third class of compounds contained ethylene dichloride, bromodichloromethane, chlorobenzene, and *o*-dichlorobenzene.

The researchers identified three major findings through the study. First, they found personal exposures were generally higher than outdoor concentrations for several of the toxic and carcinogenic compounds. This led the researchers to conclude that indoor environments were the more significant microenvironment contributing to exposure (Wallace et al, 1986). Secondly, they identified breath samples as an appropriate way to estimate levels in the body. Lastly, they found the study demonstrated the usefulness of personal monitoring in estimating population exposures and identifying potential sources (Wallace et al., 1986).

2.4.1.2 Phase III

The third phase of the TEAM Study was carried out in South Bay of the Los Angeles basin in Southern California and in Antioch, Pittsburg and West Pittsburg in Northern California. These areas were chosen because of industrial activities in close proximity to homes sampled. The sampling method and procedures used were based on techniques developed during the second phase of the TEAM Study. Twenty-six compounds were selected for analysis. Toxicity, carcinogenicity, mutagenicity, production volume, presence in ambient air and ability for collection were used as criteria for the selection process (Wallace, 1988). For the recruitment process the overall response rate was 56%. Table 2.4 and Table 2.5 summarise the combined results of personal and outdoor samples taken in California during Phase III.

The third phase had several important findings. First, 1,1,1-trichloroethane, benzene, tetrachloroethylene, ethylbenzene and xylenes were found to be ubiquitous in air and breath samples. Second, personal air concentrations were typically greater than the corresponding outdoor air concentrations. This was particularly apparent in the spring as opposed to the winter, when outdoor levels were higher. Higher winter values were observed both indoors and out, but the increase in outdoor levels was more dramatic (Hartwell et al., 1987a).

Potential sources of exposure for participants of the study were also investigated. Smoking, employment and auto-related activities were identified as major sources of exposure for the participants. In particular, smoking was identified as the main source of benzene exposure for the target population in California (Wallace, 1988). For the winter data set, passive smoking was linked to increased exposure to benzene and styrene levels in the homes of smokers.

2.4.1.3 Follow-up Study

A follow-up study was done in the South Bay section of Los Angeles, California in 1987 and included only residences sampled previously in 1984. Personal air, indoor and outdoor air samples were taken for two consecutive twelve-hour periods. Indoor and outdoor samples were collected at a fixed location, at a height of about one to two metres from the ground. Indoor samples were taken in the kitchen or dining area during the night-time and in the kitchen and primary living area during the day. Outdoor samples were taken in the backyard, away from structures if possible (Hartwell et al., 1992).

Similar to previous TEAM studies, the highest concentrations were observed for 1,1,1-trichloroethane, benzene, tetrachloroethylene, ethylbenzene, *o*-xylene, (*m+p*) xylene and limonene. This was true for personal, indoor and outdoor levels, with the exception of limonene outdoors. Limonene was relatively low outdoors. The general trend for concentrations was that personal air levels were highest, followed by indoor levels, followed by outdoor levels. Since indoor levels were consistently higher than outdoor levels, it was concluded that this was a result of indoor sources. Levels recorded during the day in living rooms and kitchens were quite similar, leading to the conclusion that diffusion and mixing of VOCs occurs rapidly inside homes (Hartwell et al., 1992). Winter concentrations were generally higher than summer concentrations. The researchers surmised that this might be a result of the intensity of photochemical reactions during summer versus winter. Daytime outdoor VOC levels were lower than night-time concentrations. The researchers suggested that this might be a result of photochemical depletion occurring during the day (Hartwell et al., 1992).

Breath samples were used as a biological marker of exposure. Concentration of VOCs recorded in the breath of an individual represents the actual total exposure resulting from absorption of pollutants from air, water and food (Hartwell et al., 1992). No consistent relationship between breath samples and personal air samples was observed.

2.4.2 Kanawha Valley

The Kanawha Valley of West Virginia is a heavily industrialised area with a large chemical manufacturing sector. An indoor study of VOCs was done in conjunction with an ambient monitoring program in an attempt to assess human exposure to VOCs. Participants were recruited through soliciting various community groups and a radio audience. The OVM 3500 (3M, Minneapolis, MN) passive sampler was used to collect three-week VOC samples inside and outside of participants homes. Samplers were placed in the master bedroom approximately 1.5 m from the floor away from open windows and local sources. Outdoor samplers were housed in aluminium shelters. Two questionnaires were used in the study, one to identify house characteristics and one to identify potential sources of VOCs. Upon collection the badges were desorbed with carbon disulphide and analysed by gas chromatography using a flame-ionisation detector. The limits of detection ranged from 1.8 to 11 $\mu g/m^3$ (Cohen et al., 1989).

Similar to the TEAM Study, indoor concentrations of VOCs were higher than outdoor concentrations, indicating that indoor sources are more important than outdoor sources (Table 2.6). Another interesting finding of the Kanawha Valley study is a group of eight compounds that were highly correlated (benzene, carbon tetrachloride, trichloroethylene, ethyl benzene, (*m+p*) xylene, *o*-xylene, trimethylbenzene, and 4-ethyltoluene). Five of the eight compounds had higher concentrations indoors in homes with attached garages. The five compounds are benzene, (*m+p*) xylene, *o*-xylene, ethyl benzene, and trimethylbenzene, and are found in gasoline (Cohen et al., 1989).

Table 2.6 Estimated median VOC concentrations from the Kanawha Valley Study (Cohen et al., 1989).

Compound	**Indoors** (μg/m^3)	**Outdoors** (μg/m^3)
Methyl chloroform	5.2	1.5[a]
Benzene	2.1	2.5[a]
Carbon Tetrachloride	3.3	2.3[a]
Trichloroethylene	2.6	1.3[a]
Tetrachloroethylene	1.3[a]	0.8[a]
Styrene	1.3[a]	0.9[a]
p-Dichlorobenzene	1.9	0.9[a]
Ethylbenzene	2.7	1.1[a]
o-Xylene	2.6	1.0[a]
(*m+p*) Xylene	7.3	2.3

[a] Below detection limit, result of fill in-method

2.4.3 Canadian Study

In 1991, Health and Welfare Canada conducted a pilot study that examined VOC levels inside and outside of typical Canadian residences (Otson et al., 1992b). A multi-stage probability sampling method was used to randomly select homes to participate in the study. The 1986 Statistics Canada census database served as the sampling frame from which homes were selected. The first stage identified census subdivisions, which were stratified to ensure representation of all major regions of the country. Enumeration areas were selected in the second stage and they were stratified to achieve representation of urban/suburban and rural homes, as well as, representation of different types of homes.

The final selection of homes within the enumeration area was done through systematic sampling.

To solicit participants, letters were delivered to the selected residences to inform the residents about the survey and the upcoming visit of a field technologist. Within approximately 24 hours, a technologist would call upon selected residences. Attempts were made a maximum of five times or until a resident either accepted or refused participation. The response rate for participation was 52% (Otson et al., 1992b).

Samples were collected using the OVM 3500 (3M, St. Paul, MN). The samplers were placed in the centre of a room, approximately 1.5 m from the floor, avoiding kitchens, bedrooms and bathrooms (Otson et al., 1992b). At the time of sampling a questionnaire was administered that dealt with characteristics of the house, occupancy and activities. Measurements of temperature and relative humidity were also recorded inside and outside during deployment and retrieval of the samplers. Upon retrieval, samplers were transported to their laboratory and analysed within 21 days to minimise storage effects (Otson et al., 1992b).

Preliminary results of the study found a high correlation between the passive samplers and the reference method (charcoal tube). The observed correlation coefficient, R^2, was 0.998 (Otson, et al., 1992). It was also found that the spatial variation of VOC concentrations in the homes was small. For 26 VOCs, the pooled standard deviation for 22 pairs of non-co-located samplers was 2.4 $\mu g/m^3$. Similarly, the standard deviation of 35 pairs of co-located samplers in the same homes was 2.2 $\mu g/m^3$.

Upon completion of the study, aliquots of the individual extracts were pooled to form a composite sample for analysis by gas chromatography-mass spectrometry. The sample was analysed for 52 volatile organic compounds and 40 were detected. Concentrations ranged from <1 μg/m^3 to 104 μg/m^3 (aniline) (Otson et al., 1994). The results of selected organic compounds from the composite sample as well as the average of 757 individual badges are summarised in Table 2.7.

Table 2.7 Results from Canadian Study (μg/m^3) (Otson et al., 1994).

	Composite	Average of Individual Badges
Benzene	12	5
n-Decane	54	31
Tetrachloroethylene	<2	3
Toluene	41	41
Ethylbenzene	12	8
1,3,5-Trimethylbenzene	5	3
Chloroform	9	2
1,2,4-Trimethylbenzene	20	12
α-Pinene	42	23
d-Limonene	33	20
o-Xylene	8	6
p-Dichlorobenzene	18	19
m-Xylene	7	14
p-Xylene	6	6
Naphthalene	12	4

2.4.4 German Study

From April 1986 to April 1987 VOCs were monitored in 12 homes in Berlin for 26 two-week periods. The study made use of passive samplers hung in the middle of living rooms 2 m above the ground. Gasbadge (National Mine Service Co., Oakland, PA) passive samplers were used at the beginning of the study, with the remainder of the study being carried out using OVM 3500 (3M, St. Paul, MN) passive samplers when the Gasbadge was discontinued. The Gasbadge and OVM 3500 passive samplers were sampled simultaneously to test their compatibility, which was found to be acceptable.

Good agreement was also observed between the passive techniques and active sampling. The samplers were extracted with carbon disulphide and analysed by gas chromatography with flame ionisation and electron-capture detection (Seifert et al., 1989).

From their analysis of the data, the researchers concluded that occupants or their activities generate approximately 50% of the total VOC concentration and the rest was due to emissions from other indoor sources. A significant difference between smokers' and non-smokers' homes could not be identified, but it was concluded that this may be a result of the small sample size. Another conclusion drawn in the study was that the main source of benzene in the homes studied was from ambient air. This conclusion was drawn because benzene levels were similar in all of the homes (Seifert et al., 1989).

2.4.5 Study Design Considerations

Review of studies that examined VOC concentrations indoors and outdoors yielded several important considerations for the design of this study. A theme that was common to two of the studies was the use of stratified probability sampling. Both the TEAM studies and the Canadian study used stratified probability sampling to randomly select potential participants (Wallace et al, 1986 and Otson et al, 1992). Based on the sampling techniques employed in the TEAM studies and the Canadian study a suitable stratified probability sampling method was developed for this study.

The importance of questionnaires was also identified from the review. Questionnaires were administered in the TEAM studies, the Kanawha Valley study and the Canadian study (Wallace et al., 1986; Otson et al, 1992; and Cohen et al., 1989). The questionnaires were used in all three studies to identify household characteristics and potential sources. These common themes served as the basis for the questionnaires used here.

Another important consideration was the use of controls for examining the effects of industrial activities. The study done in the Kanawha Valley of West Virginia used control samples to examine the potential effects that the chemical industry may be having on human exposure (Cohen et al, 1989). Out of 35 homes sampled four were outside of the Valley and were selected to serve as controls for comparison. This study took this approach a step further and sampled an entire community to serve as a control. Sampling similar numbers of homes in each community facilitated a statistical comparison of the two areas.

Lastly the review identified some minor considerations which aided in the execution of the study. For example a height of 1.5 m for sampler placement within the homes was applied, which is consistent with the heights used in the Kanawha Valley study and the Canadian study. Moreover, the Canadian study made use of a letter to residents to inform them of the study and the upcoming visit from a field technologist (Otson et al., 1992b). This approach was also used in St. Albert and Sherwood Park in an attempt to prepare homeowners for the arrival of researchers requesting their participation. Another idea obtained from the review process was measuring temperature and relative humidity during deployment and retrieval. This approach was taken during the Canadian study as temperature and relative humidity can affect the samplers.

Chapter 3: Sample Collection

3.1 Statistical Design

Two communities were chosen for this study based on their proximity to a large industrial sector. Sherwood Park was chosen as the study area because it is in close proximity to industrial emissions. The city of St. Albert was selected to serve as a control community because it is considered not to be in close proximity to the industrial sector. Figure 3.1 shows the relative locations of Sherwood Park and St. Albert to one another and the industrial corridor. The major industries in the area are highlighted with stars.

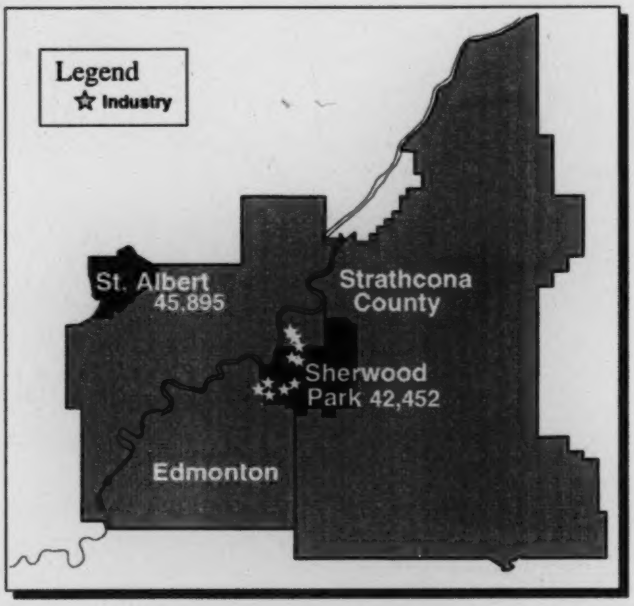

Figure 3.1 Study areas.

The sampling method chosen for this study was probability sampling. Probability sampling involves the random selection of units from a population. The final statistical design involved the combination of two probability sampling schemes: stratified sampling, and systematic sampling. Stratified sampling divides or stratifies a population into relatively homogenous groups called strata. From these strata, samples are independently selected (Satin and Shastry, 1990). Systematic sampling involves the random selection of a starting point and sampling takes place at a set interval (Satin and Shastry, 1990 and EPA, 1984).

The main reason for using a stratified sampling method was to ensure a good geographical distribution of samples. If a stratified sample was not used, by pure chance all the homes selected for sampling may have fallen in one area of each of the communities. Using the stratified sampling method also allows comparisons to be made amongst the strata. For example, comparisons can be made based on proximity to industrial emissions within the communities. In addition, stratified sampling improves the operational feasibility and efficiency of the field sampling process.

Variations on probability sampling methods were employed in both the Canadian (Otson et al., 1992b) and TEAM studies' (Wallace et al., 1986) statistical designs. Both of these studies had three stages and used stratification. The methods used in each study were discussed earlier.

The statistical design for this study was a three stage stratified probability sampling method with the last sampling stage involving systematic sampling. The three strata were 1) Industrial Proximity Strata, 2) Geographical Strata, and 3) Individual House Strata. When stratifying the two communities, an assumption was made that any part of the sampling area would be representative of the whole area.

The first stage involved dividing each community based on proximity to industrial emissions (Figure 3.2 and Figure 3.3). Sherwood Park was divided into four proximity strata and St. Alberta had three proximity strata. The second stage divided the proximity strata based on geographical area (Figure 3.2 and Figure 3.3). The purpose of the geographical strata was to ensure good distribution among the communities and improve the operational feasibility. Eight geographical strata were designated in each community. The geographical strata are designated numbers 1 to 8 for St. Albert and numbers 9 to 16 for Sherwood Park. Using geographical strata ensured samples were taken in all corners of the communities. As well, it divided the community into more manageable areas for the third stage of the selection process.

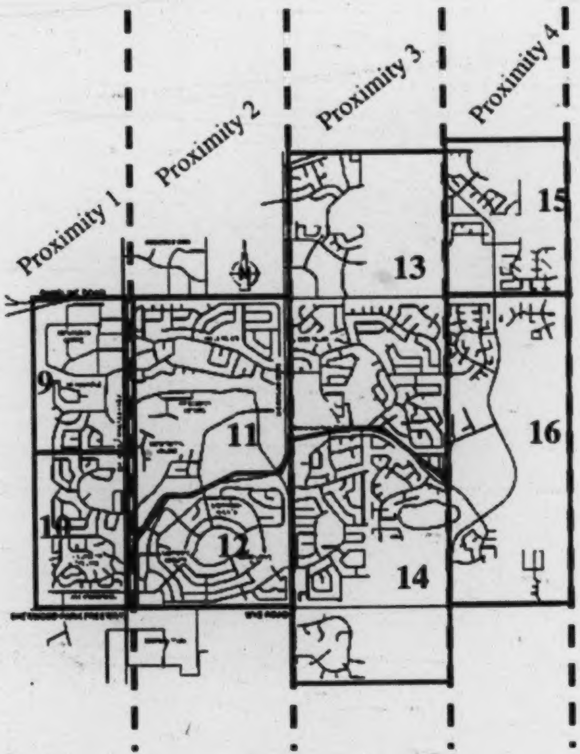

Figure 3.2 Sherwood Park study Areas.

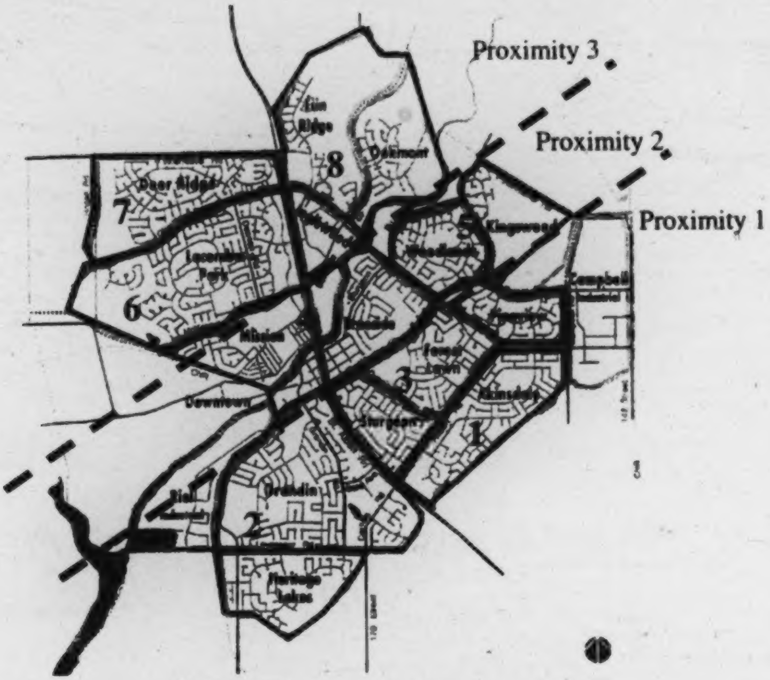
Proximity 3
Proximity 2
Proximity 1
8
Erin Ridge
Oakmont
Deer Ridge
7
Lacombe Park
6
Mission
Kingswood
Woodlands
5
Campbell
Forest Lawn
3
Akinsdale
Downtown
Sturgeon
1
Grandin
Riel
2
Heritage Lakes

Figure 3.3 St. Albert study areas.

The third stage was the random selection of homes within each of the geographical strata. For this stage, systematic sampling was used. The starting point was randomly selected and an interval of one was used. An interval of one was used to increase efficiency when out in the field because there was no guarantee that the adjacent house would participate in the study. To perform the random selection of homes, lists of all the homes were obtained from each of the communities, excluding apartment buildings. These lists were imported into Excel© format where Excel's© Random function was used. From each of the geographical strata a single home was randomly selected. These homes served as the starting points for the recruitment process. Apartment buildings were neglected because they may have introduced an additional source of error. Apartments made up 9% and 3% of St. Albert and Sherwood Park dwelling units respectively; therefore, it was assumed that their omission would have a negligible effect (Table 3.1).

Table 3.1 Occupied dwelling units by type (ED&T, 1999; CPS, 1999).

Dwelling Type	St. Albert	Sherwood Park
	(1998 Census)	(1998 Census)
Single Family	76%	87%
Duplex/Fourplex	3%	4%
Townhouse	12%	6%
Apartment	9%	3%

An equal number of samples were taken in each industrial proximity strata, within the communities. This resulted in 32 homes in Sherwood Park (8 per strata) and 30 homes in St. Albert (10 per strata). A minimum of 30 homes in each community was desired so that the central limit theorem could be applied to the data. The central limit theorem states that the sampling distribution of the sample mean will be approximately normal if the sample size is large enough (Johnson, 1994). Traditionally, a sample size is considered large if it is equal to, or greater than 30.

The number of homes to be sampled in any given geographical area was determined based on the number of homes in that area. The percentage of the industrial proximity that a geographical area represented determined the number of homes to be sampled in that area. For example, if Area 1 is 22% of Proximity 1, multiplying 0.22 by the number of homes to be sampled in Proximity 1 (10 homes), yields 2 homes to be sampled in Area 1. This process was performed for all areas, in both communities. The distribution of homes and the number of homes to be sampled in St. Albert and Sherwood Park are outlined in Table 3.2.

Table 3.2 **Sampling distribution.**

	Dwelling Units	% Industrial Proximity	Samples per IP
St. Albert			
Industrial Proximity (IP) 1			
Area 1	1639	22%	2
Area 2	3609	47%	5
Area 3	2349	31%	3
IP Total	7597		10
Industrial Proximity 2			
Area 4	1714	60%	6
Area 5	1124	40%	4
IP Total	2838		10
Industrial Proximity 3			
Area 6	2165	48%	5
Area 7	1374	30%	3
Area 8	987	22%	2
IP Total	4526		10
Sherwood Park			
Industrial Proximity 4			
Area 9	989	42%	3
Area 10	1367	58%	5
IP Total	2356		8
Industrial Proximity 5			
Area 11	1928	56%	4
Area 12	1503	44%	4
IP Total	3431		8
Industrial Proximity 6			
Area 13	2530	57%	5
Area 14	1895	43%	3
IP Total	4425		8
Industrial Proximity 7			
Area 15	1391	52%	4
Area 16	1267	48%	4
IP Total	2658		8

3.1.1 Recruitment Process

Based on the random starting points, a systematic sampling approach was taken to recruit volunteers. Volunteers were recruited in the communities by going to the randomly selected homes first and then proceeding to the house on the immediate right until the correct number of homes were obtained through volunteers. Recruitment started by initially delivering a brochure about the study (Appendix 8.1). A brochure was delivered prior to visiting the houses in an attempt to inform the residents of the study and inform them of the upcoming visit. This approach was also used during the Canadian study by delivering a letter approximately 24 hours prior to a visit (Otson et al., 1992b). A 50% success rate was assumed, therefore brochures were delivered to double the number of homes required in any given area. Drop-off of the brochures was followed up with visits to the homes. Homes were approached a maximum of three times if there was no answer. Visits to the homes were logged as an attempt, consent or rejection. If an attempt was made but no one was home, a leaflet was left behind to inform the resident of the attempt and inform him or her that a second attempt may be made (Appendix 8.2). The residents were also encouraged to call the number provided on the leaflet if they had any questions about the study. Table 3.3 outlines the success of the recruitment process. A success rate of 45% was observed for the fall recruitment process. Recruitment was done weekday evenings and Saturday afternoons. The entire process took two weeks.

Table 3.3 **Fall recruitment success rate.**

	Overall		**St. Albert**		**Sherwood Park**	
	Count	**Percentage**	**Count**	**Percentage**	**Count**	**Percentage**
Consent	62	45%	30	52%	32	40%
Attempts	37	27%	17	29%	20	25%
Rejections	36	26%	9	16%	27	34%
Drop-outs	3	2%	2	3%	1	1%
Total	138		58		80	

During the sampling break between fall and winter sampling phases two participants were lost, in addition to those lost in the fall, due to unscheduled moves. As a result, two additional volunteers needed to be recruited in January. To obtain new participants the homes where the volunteers were lost were approached first in hopes of finding new owners willing to participate. Success was achieved at one of the homes; but a new home had to be recruited to compensate for the loss of the second home. The second home remained empty during the winter sampling period. The recruitment process picked up where it left off in the fall for the neighbourhood where the volunteer was lost. Six homes were approached until a volunteer was found.

3.1.1.1 Recruitment Procedures

To recruit volunteers, residents were given a verbal overview of the study. If the resident was not interested, they were thanked for their time and the process was repeated at the next house. However, if the resident was interested in the study they were presented with a letter from the primary investigator Dr. Warren Kindzierski and the Medical Officer of Health with the Capital Health Authority, Dr. Gerry Predy. The purpose of the letter was to inform the resident of the validity of the study and encourage them to participate. An information sheet was also provided which outlined the details of the study and the role of the participants. The information sheet also contained a phone number, other than the investigators, that could be called if a participant had any concerns regarding the nature or the validity of the study. The recruitment package is provided in Appendix 8.3.

The information sheet was read aloud with the resident and at the end they were asked if they wished to participate. Once consent was obtained, the resident was asked to read through and sign the consent form (Appendix 8.4). After the consent form was signed they were given a research identification number and a sampling date was scheduled. The *Household Characteristics* questionnaire was also given out at this time. This process was repeated until 62 homes were recruited.

3.2 Questionnaires

Questionnaires are a useful tool when assessing human exposure. Different types of questionnaires can indirectly measure exposure by identifying physical characteristics about microenvironments, identifying potential sources of exposure and determining activity patterns of individuals (NAS, 1991). Questionnaires were used in both the Canadian Study and the TEAM Studies done in the United States (Otson et al., 1992b and Wallace et al., 1986). The Canadian Study used a questionnaire to identify characteristics of the homes being sampled. For example, questions regarding home age and type, ventilation systems, occupancy and renovations were included in the Canadian study's questionnaire. In comparison the TEAM Study used a set of questionnaires. The first questionnaire was used to screen potential participants. The second identified the characteristics of the home as well as the individuals living in the house (e.g. smoker, occupation, and heating/ventilation). A 24-hour recall questionnaire was the third and final questionnaire; it was used for participants of personal monitoring. This questionnaire's purpose was to identify all potential exposures occurring during the sampling period.

Prior to conducting the Canadian study a potential questionnaire was field tested. Questionnaires were sent to participants one month prior to sampling, to be completed before sampling. The researchers discovered that the questions needed to be well defined and that a trained individual should administer the questionnaire. The questionnaires used during the field test were often returned incomplete and of varying quality (Otson et al., 1992b).

For this study, in Sherwood Park and St. Albert, three questionnaires were developed. The questionnaires were developed using formats developed for the Alberta Oil Sands Community Exposure and Health Effects Assessment Program (AOSCEHEAP, 1995), and a standard Environmental Inventory Questionnaire (NAS, 1991) as guides. The first questionnaire given to participants, *Household Characteristics* (Appendix 8.5) was designed to identify characteristics of homes sampled. Questions regarding habitants of the house, type of house, heating, ventilation and air conditioning (HVAC) systems and attached structures were included. This questionnaire was given to individuals when they agreed to participate in the study. Participants were then instructed that it would be collected when the samplers were deployed. To elicit satisfactory responses a glossary of terms was included with the questionnaire and the questions were primarily limited to Yes/No answers. However, space was provided for comments in case an individual did not feel a simple yes or no would suffice.

The second questionnaire, *Household Activities* (Appendix 8.5) identified potential sources of VOCs within the house. Household sources such as large appliances (cooking stove, hot water heater, and clothes dryer) and carpeting were identified. These questions were followed up with questions pertaining to specific activities. Activities included smoking, picking up dry-cleaning, professional cleaning (drapes, carpet, furniture), hobbies and renovations. In addition, specific items, such as gasoline, paint and cleaning agents, were identified as to possession, storage location, recent use and location of use. The second questionnaire was done in the form of an interview when the samplers were retrieved. An interview style was chosen to elicit adequate responses.

The third questionnaire, *Changes to Household Characteristics and Household Activities* (Appendix 8.5), was a follow-up to the first two questionnaires. Any changes in the characteristics of the house or changes in potential sources were identified. The first part of the questionnaire identified renovations, as well as, changes to HVAC systems, appliances and habitants of the house. The remainder of the questionnaire repeated the activities section of the second questionnaire discussed earlier. The interview approach was used again for this questionnaire.

The three questionnaires used throughout the course of the study are presented in Appendix 8.5. Although the questionnaires were not fully analysed in this study, they served as a source of information for any anomalies identified in the data.

3.3 Passive Sampling

Passive sampling, also known as diffusive sampling, is a technique whereby the chemical constituents of the air are collected on a sorbent aided only by diffusion (NAS, 1991). In comparison, active sampling involves the use of a pump to pull air through a collection device (NAS, 1991). Passive samplers have been used in several studies of organic compounds (Cohen et al., 1989; Seifert et al., 1989; and Otson et al., 1992b). One advantage of using passive samplers is their small size. Their size allows the samplers to be placed inside homes and be unobtrusive to the occupants. As well, they are convenient for the researchers during deployment. The samplers are also relatively inexpensive, allowing numerous homes to be sampled concurrently. Another significant advantage is that they do not require any additional equipment for operation. No pumps, electricity or calibration equipment is necessary (NAS, 1991). The passive samplers are also silent which makes them more attractive to participants.

Despite their advantages, passive samplers have some disadvantages as well. In order to collect a sufficient amount of sample, sampling times need to be longer than those used during active sampling. Passive monitoring sampling times vary from 1 hour in an occupational setting, up to 4 weeks in an ambient setting. In addition, passive samplers have also been known to give less accurate results than active samplers do (NAS, 1991). Lastly, the potential for chemical transformations on the sorbent exists. This becomes more important as the sampling time increases (NAS, 1991).

3.3.1 Theory of Diffusive Sampling

The uptake rate for passive samplers is based on Fick's First Law of Diffusion (Moore, 1987). The equation developed for passive samplers uses the geometry and the diffusivity of the gases to be sampled to calculate the uptake.

$$Q = \frac{DA}{L(C_0 - C_e)T} \qquad \textbf{Eq. 3.1}$$

where

D = coefficient of diffusion (cm^2/s)
A = cross sectional area of diffusion path (cm^2)
L = length of diffusion path (cm)
C_o = ambient concentration (g/cm^3)
C_e = concentration at the sorbent interface (g/cm^3)
Q = mass uptake (g)
T = sampling time (s)

Based on Equation 3.1 a sampling rate can be calculated for a fixed geometry if the diffusion coefficient is known. Sampling rate is represented by DA/L. Based on this definition of sampling rate, it could be presumed that either increasing the cross sectional area (A) or decreasing the diffusion path length (L) could infinitely increase sampling rate (Moore, 1987). However, this is limited by practicality. For example, increasing A is limited because one of the advantages of passive samplers is their small size. Decreasing the path length is also limited because the relationship between diffusion path length and sampling rate is not linear (Moore, 1987).

Tompkins and Goldsmith (1977) developed an expression that predicts the maximum practical sampling rate based on mass transfer properties instead of A and L considerations.

$$\text{mass uptake} = kAC_0 \qquad \textbf{Eq. 3.2}$$

where k = convective mass transfer coefficient

In 1973, Palmes and Gunnison attempted to show the applicability of passive samplers for personal monitoring. The experiments involved varying the diffusion path lengths and the areas for several samplers. The samplers were tested with water vapour and sulphur dioxide and had encouraging results. Upon examination of Palmes and Gunnison's results, Moore (1987) discovered that the samplers that failed the tests had sampling rates calculated from A/L exceeding the maximum allowable sampling rates based on mass transfer (kA). This means that if the sampling rate is too great, the microenvironment will not be able to supply the sampler fast enough.

3.3.2 OVM 3500

The passive monitor chosen for this study was the OVM 3500 (3M, St. Paul, MN). It has been used in several other indoor air quality studies (Cohen et al., 1989; Otson et al., 1992b; and Seifert et al., 1989) and has been thoroughly tested for potential sampling biases (Tang et al., 1993; Gagner, 1996; Otson et al., 1992a; and 3M, 1997 and 1998). The OVM 3500 monitor is a diffusive air sampler designed for personal and area monitoring. It measures average concentrations over a measured time interval (3M, 1996a). The monitor is a small circular badge that contains a charcoal absorbent pad and has a clip for attaching the monitor to shirt collars. Figure 3.4 is a schematic of the OVM 3500.

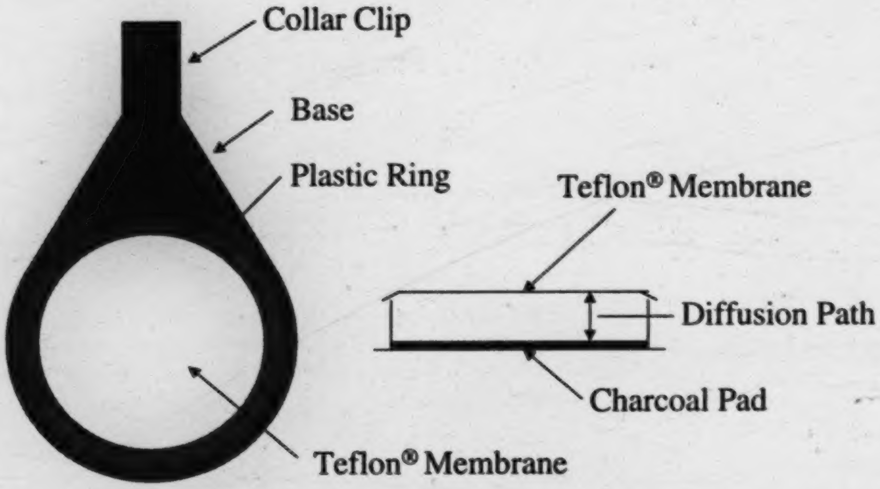

Figure 3.4 Schematic of OVM 3500.

The badges are shipped to the customer in an evacuated sealed container and sampling begins once the container is opened. By diffusion, chemical compounds present in the air pass through the Teflon membrane and are collected on the charcoal pad. The Teflon membrane is a barrier that provides clear separation between the medium being sampled and the path length over which diffusion to the charcoal pad occurs.

The following sections outline the potential factors affecting sampling and the applicability of passive samplers and in particular the OVM 3500, for monitoring indoor and ambient environments.

3.3.3 Sampling Bias

Passive samplers can potentially be affected by several factors. Temperature, relative humidity, storage time and face velocity can all affect sampling efficiency. The effect of sampling for a mixture of compounds, as well as, the affects of concentrations within the air have also been examined as potential sources of bias.

3.3.3.1 Temperature

Diffusion coefficients are proportional to temperature, with molecular diffusivity increasing with increasing temperature (Pozzoli and Cottica, 1987). Tang et al. (1993) evaluated the performance of the OVM 3500 for styrene under varying controlled conditions. When the temperature was increased from 10°C to 23°C and 36°C, the sampling rate increased from 33.3 mL/min to 36.0 mL/min and 39.0 mL/min, respectively (Tang et al., 1993). Gagner (1996) examined the effect of temperature when sampling for toluene and benzene and found that a correction factor was not necessary below -15°C.

All formulas developed for use with the OVM 3500 are based on a sampling temperature of 25°C. For every 5 to 6°C above or below 25°C, a one percent correction of the time-weighted average concentration is required (3M, 1998).

A standard temperature probe was used to measure the temperature within the homes being sampled (Figure 3.5). The temperature probe was placed in the centre of the room upon arrival at a home and allowed to equilibrate while a sampler was being deployed or retrieved. Care was taken to ensure the probe was not in direct sunlight as this gave false readings.

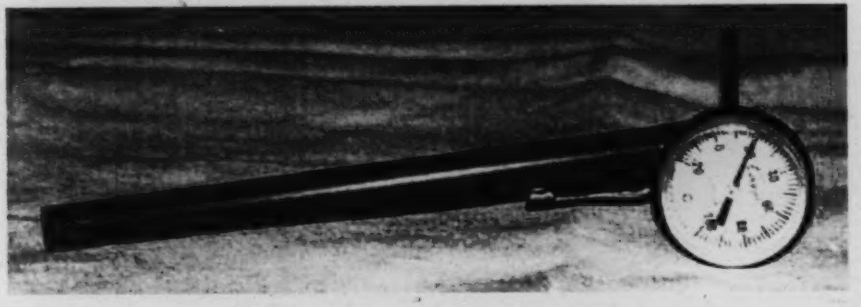

Figure 3.5 Temperature probe.

3.3.3.2 Relative Humidity

Relative humidity (RH) can affect the adsorption capacity of the sorbent. A limit of interference of approximately 50% relative humidity has been suggested for passive samplers (Pozzoli and Cottica, 1987). Relative humidity was examined by Tang et al. (1993) and it was determined that sampling rate decreased when the relative humidity was increased. However, it was noted that the difference was less than 10%. During the study done by Gagner (1996) high relative humidity was found to affect the badge performance; however, the extent was minimal and considered inconclusive.

The capacity of the OVM monitor is based on dry conditions (<50% RH) and 3M states that high relative humidity may significantly reduce the capacity and sampling time of the monitor (3M, 1998). 3M examined the effects of sampling at a high humidity (80% RH) on the recovery efficiency. It was found that most of the compounds examined were not significantly affected by the high humidity when stored at room temperature for up to 3 weeks (3M, 1996b). The exceptions were ketones and compounds with double bonds (acetone, diethyl ketone, 2-hexanone, methyl ethyl ketone, methyl propyl ketone and vinyl acetate). These compounds were susceptible to losses.

A Q-Trak™ IAQ Monitor, Model 8551 (TSI Incorporated, St. Paul, MN) was used to measure relative humidity in the homes being sampled. Figure 3.6 is a picture of the Q-Trak™ used during the study. Measurements were taken when a passive sampler was deployed and when it was retrieved. The Q-Trak™ is capable of measuring a range of 5 to 95% RH, ±3% RH. The sensor is a thin-film capacitive and has a response time of 20 seconds. In addition to allowing sufficient time to equilibrate when measuring relative humidity, intense light such as direct sunlight needed to be avoided otherwise the sensor would not function properly (TSI, 1997).

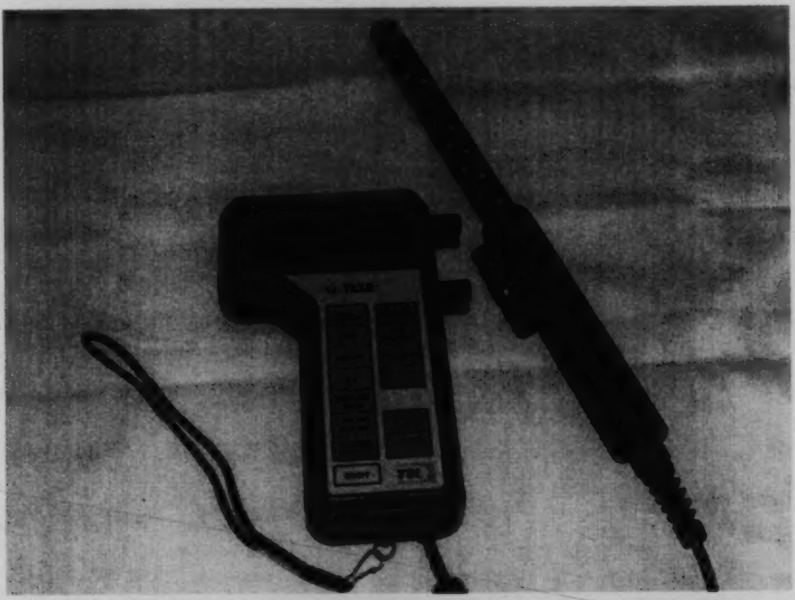

Figure 3.6 Q-Trak TM IAQ monitor, Model 8551.

3.3.3.3 Face Velocity

In order to achieve continuous collection, the pollutants within the air must be continuously brought to the sampler's contact surface through physical forces (Pozzoli and Cottica, 1987). The goal is to reduce the boundary layer to near zero, allowing the concentration gradient to remain the driving force for diffusion (Brown, 1993). If a constant supply of air is not supplied, the sampler will in essence starve. A minimum face velocity recommended for most passive samplers is between 0.05 m/s and 1.0 m/s (Harper and Purnell, 1987).

Tang et al. (1993) found a slight increase in sampling rate when the face velocity was increased, but for the OVM 3500 the variations were less than 10%. In addition, the researchers noted that the OVM 3500 performed well with a face velocity of 0.01 m/s (Tang et al., 1993). The minimum face velocity recommended by 3M is 0.13 m/s (3M, undated). Otson and Fellin (1991) also examined the effect of face velocity on the sampling rate for several different passive samplers. Tests were done at velocities of 1.8, 0.5 and approximately 0.01 m/s and the sampling rates showed a less than 10% variation. In particular, the OVM 3500 performed consistently well over the range of face velocities examined (Otson and Fellin, 1991).

3.3.3.4 Storage

The study done by Tang et al. (1993) also examined the effects of storage. Three sets of samplers were exposed and the first set was analysed immediately. The other two sets were stored at room temperature and analysed 7 and 21 days later, respectively. For the collection of styrene with an OVM 3500 the observed losses were less than 16% (Tang et al., 1993).

When sampling for most compounds using the OVM 3500, the samplers may be stored for up to three weeks at room temperature. However, compounds such as ketones and those with double bonds may need to be refrigerated to reduce losses due to adsorbed water (3M, 1996b).

3.3.3.5 Fluctuating Concentrations

Concern exists as to whether fluctuating concentrations at the sampler's interface affects the sampling efficiency. Hori and Tanaka (1993) studied the effect of fluctuating organic vapour concentrations on a passive sampler. No significant difference was observed between measurements taken under fluctuating or steady concentrations (Hori and Tanaka, 1993). Similarly, during the study done by Gagner (1996) at subzero temperatures, the OVM 3500 was responsive to fluctuations in VOC concentrations.

3.3.3.6 Mixtures of Compounds

Interactions between the various compounds being sampled may also cause problems in sampling efficiency and desorption efficiency when using passive samplers. Ballesta et al. (1992) examined the effect of sampling for a mixture of compounds, instead of sampling for a single compound. Passive sampling for a mixture of toluene, hexane, methyl ethyl ketone and ethyl acetate on activated carbon was compared to passive sampling for the individual compounds. Variations between a mixture and individual results were observed; however the deviations were within 10% (Ballesta et al., 1992).

3.3.4 Sorbents

Several inorganic and organic sorbents are available for use in passive samplers. Examples of inorganic sorbents are silica gel, alumina, magnesium aluminium silicate and molecular sieves (Keith, 1991). These types of sorbents are effective at collecting polar organic compounds, but they also collect water as easily leading to rapid sorbent deactivation. Inorganic sorbents can cause isomerization of organic compounds. For these reasons inorganic sorbents are not often used when collecting VOCs (Keith, 1991).

Examples of organic polymeric sorbents are a porous polymeric resin of 2, 4-diphenyl-p-phenylene oxide (Tenax®-GC), styrenedivinylbenzene copolymer (XAD) resins and polyurethane foam (PUF) (Keith, 1991). An advantage of organic sorbents is their low affinity for water.

Activated carbon is another common sorbent material. An activated carbon tablet is what is used in the OVM 3500. Water is less of a problem than for inorganic sorbents, but in instances where the relative humidity is high, the adsorption capacity of the monitor may be affected. Certain organic compounds may not be desorbed easily from activated carbon and the high surface area of activated carbon can promote reactions (Clements, 1988).

3.3.5 Validation

Several studies have tested the validity of passive samplers, and in particular the OVM 3500 for use in indoor and outdoor studies (Otson et al., 1992b; Cohen et al., 1990; Shields and Weschler, 1987; Seifert and Abraham, 1983; and Coutant and Scott, 1982). Earlier studies found passive samplers inadequate for monitoring ambient concentrations, but more recent studies have proven their usefulness. Coutant and Scott (1982) examined three passive samplers, including the OVM 3500, and found them inadequate at ambient levels due to their detection limits and blank levels. However, the researchers did note that if lower detection limits and blank levels were achieved the monitors could be quite useful (Coutant and Scott, 1982).

Seifert and Abraham (1983) examined the usefulness of passive samplers for indoor air. The passive samplers were tested using a mixture of compounds with concentrations ranging from 75 to 5000 μg/m^3. To determine the variation in amount trapped on the sorbent, an exposure of 24 hours and individual hydrocarbon concentrations between 150 and 600 μg/m^3 were used. The amount of compounds trapped by the sorbent varied between 5 and 10%. This study also examined the effect of leaving a loaded badge exposed to an unpolluted atmosphere. It was found that once loaded, the sorbent did not release the adsorbed compounds even when left for a couple of days (Seifert and Abraham, 1983).

The OVM 3500 was examined by Shields and Weschler (1987) for ambient concentrations over four to eight weeks of sampling. This study concluded that precision of the OVM monitor was sufficient to detect major differences in concentration between indoors and outdoors. In addition, it was concluded that the monitor could sample ambient concentrations over several weeks and that the reproducibility was about 13% of the mean concentration (Shields and Weschler, 1987).

Cohen et al. (1990) investigated the OVM 3500 under laboratory conditions to examine its validity for a three week sampling period. The monitor was tested with concentrations of 10 and 100 μg/m^3 and relative humidity of 25% and 75%. The monitor was found to perform best under high concentration with low relative humidity and low concentration with high relative humidity. Results from the OVM 3500 were also compared to the average from an active sampler and the predicted value in an exposure chamber. Differences of less than 25% were observed under the majority of conditions tested (Cohen et al., 1990).

Otson et al. (1992a) tested the applicability of the OVM 3500 for indoor air quality studies. Samplers were placed in homes for 23 to 96 hours during summer and winter. Based on samples collected the method detection limit (MDL) was estimated to be approximately 2 μg/m^3 and the practical quantitation limit (PQL) was estimated at approximately 10 μg/m^3, for most of the VOCs studied. Based on the high precision and high correlation with an active sampling method, the researchers concluded the OVM 3500 would be useful for monitoring an indoor environment (Otson et al., 1992a).

3.4 Factors affecting Indoor Sampling Location

Samplers were placed inside and outside homes in Sherwood Park and St. Albert. The general locations for sampling were determined prior to heading out into the field by examining factors that could influence sampling efficiency.

In order to obtain representative indoor samples many factors required consideration. Keith (1991) identified four considerations necessary when sampling indoors:

- sampler location within a room;
- normal activities within the room;
- history of activities that may add compounds (e.g. cleaning); and
- ventilation systems.

To control the effects of sampler location an attempt was made to place the samplers in similar locations in each house, acknowledging that none of the houses were exactly the same.

The usual activities within a room being sampled were not controlled, volunteers were asked not to change their living habits. By choosing a central living area, it was believed that all of the sampling locations would be influenced by similar activities. Samplers were placed in a central area, on an inside wall near the kitchen and living room. In order to identify activities that may have introduced VOCs into the house, the second questionnaire was always administered.

3.4.1 Ventilation

Ventilation systems can alter the airflow in a room and add or reduce the levels of pollutants. A study done by Matthews et al. (1989) examined airflow in the kitchen, master bedroom and basement, at heights between 0.9 and 1.4 m. The study concluded that air velocities can range from near stagnant conditions (e.g. 0.5 cm/s) to 50 cm/s in a residential indoor environment depending on HVAC systems and occupant activities. The highest velocities were typically found in the kitchen and HVAC system operation had only a small affect on velocities. The researchers also concluded that low velocities may limit off-gassing from evaporation controlled sources (Matthews et al., 1989).

A study done by Kovanen et al. (1989) studied the characteristics of turbulent airflow in occupied, ventilated spaces at heights of 0.05, 0.15, 1.1 and 1.7 m. It was concluded that in occupied ventilated spaces airflow fluctuates at random. In addition, it was found that the airflow at heights of 1.1 and 1.7 m was nearly laminar with low mean velocity (<0.1 m/s) (Kovanen et al., 1989).

Ventilation systems were not controlled in this study; however the type of HVAC system in each home was recorded in the questionnaires. As well, during the interview it was asked whether windows had been open over the sampling period.

3.4.1.1 Carbon Dioxide (CO_2) Measurements

Carbon dioxide was measured to serve as a general indicator of ventilation. Several different approaches have been developed that use indoor carbon dioxide concentrations to determine a building's ventilation (Persily, 1997). However, for this study no attempts were made to quantify ventilation.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has a guideline for indoor carbon dioxide of 1000 ppm (Persily, 1997). This guideline is not based on health or comfort effects, rather on association with human body odour (Persily, 1993). The guideline was developed by assuming that humans are the only source of carbon dioxide within a building, the ambient CO_2 concentration is 300 ppm and the design residential ventilation rate is 15 cfm per person (Walkinshaw, 1992). When recording CO_2 levels an assumption was made that if the CO_2 concentration was at or below 1000 ppm the home had adequate ventilation. However, this does not imply that ventilation was sufficient to reduce indoor sources of other indoor contaminants. If a home had adequate ventilation, it was assumed that the air was not stagnant and thus the air in the home was well mixed. These assumptions were important when locating the sampler within the house. If the air was well circulated a sufficient face velocity should have existed for the sampler and it should not have been significant whether the sampler was placed in the living room or a bedroom.

The Q-Trak™ IAQ Monitor, Model 8551 (TSI Incorporated, St. Paul, MN) was used to measure carbon dioxide concentrations in homes being sampled. Figure 3.6 is a picture of the Q-Trak™ used during the study. Measurements were taken when a passive sampler was deployed and when it was retrieved. The Q-Trak™ used to measure carbon dioxide had a Non-Dispersive Infrared sensor with a range of 0 to 5000 ppm and an accuracy of ±3% at 25°C. The response time of the Q-Trak™ is 20 seconds to reach 63% of the final value (TSI, 1997). Therefore, when the measurements were taken the sensor was allowed to equilibrate for a minimum of 2 minutes.

3.5 Factors Affecting Outdoor Sampling Location

When sampling outdoors the meteorological conditions can affect sampling efficiency. The main conditions that need to be considered when doing ambient sampling are wind direction, wind speed, temperature, atmospheric stability, atmospheric pressure and precipitation (Keith, 1991). Wind direction is particularly important for this study because it is the pollutants from the industrial corridor that are under investigation. Pollutant concentrations may vary depending on which way the wind is blowing. Wind speed and temperature can affect pollutant concentrations by increasing volatilisation, which in turn increases atmospheric concentrations. However, increased wind speeds can also increase dilution. Atmospheric stability affects pollutant dispersion by changing the vertical motions of the atmosphere. Stable conditions can lead to higher concentrations downwind due to less mixing. Atmospheric pressure is primarily a concern for the release of gases from landfills. Volatile compounds can be released more readily from landfills during low pressure conditions; however this effect may be limited if the pressure change occurs over a long period (Keith, 1991). This may be of importance because a landfill is located in the industrial area, approximately 7 km from Sherwood Park. Lastly, precipitation will reduce the amount of contaminants in air. Particulate matter will be physically carried down while gases will dissolve in the water droplets (Keith, 1991). In order to account for potential effects resulting from meteorological conditions, local meteorological data was obtained from Environment Canada for the two sampling periods.

3.5.1 Sampling Procedures

Once the recruitment phase was completed and all the participants were scheduled the sampling program began. Sampling was scheduled during the day and the evening. For the fall sampling period, five homes were sampled during the evenings, three in one community and two in the other. The maximum number of homes sampled during one day was ten. For the winter sampling period, the number of homes sampled in the evening was reduced to four and a maximum of eight homes a day. The sampling instructions are summarised in Figure 3.7 and Figure 3.8, and outlined below.

OVM 3500 Sampling Instructions

1. Remove monitor from can.
2. Record monitor serial number, sampling date, research ID number, temperature, relative humidity and start time in logbook.
3. Record sampling date, research ID number and start time on monitor label.
4. Hang monitor on the wall inside or on stand outside.
5. At end of sampling period, remove plastic ring and white film from monitor.
6. Snap elution cap onto monitor, ensuring both port plugs are secured and record final sampling time on monitor and in logbook.
7. Return monitor to can and close with plastic lid.

Figure 3.7: Sampling instructions based on 3M recommendations (3M, 1996a).

Field Procedures

1. Arrive at volunteer's home at pre-scheduled time.
2. Discuss any questions participant may have.
3. Go over Part I of questionnaire.
4. Select sampler location.
5. Deploy sampler inside and out, as per 3M recommended procedures.
6. Return 24 hours (±0.5) later to retrieve monitor.
7. Retrieve sampler as per 3M procedures.
8. Seal can with Teflon tape.
9. Complete Part II of questionnaire and collect Part I.
10. Thank participant.
11. Return samplers to the lab and place in refrigerator (4°C).

Figure 3.8: Field procedures for Phase I and II sampling periods.

Upon arrival at a volunteer's home, at a pre-scheduled time, any questions a participant may have were discussed. The home was then surveyed for a suitable location to place the sampler. Samplers were placed on an inside wall, in a central location within the house. A typical location was on a wall near a doorway between a kitchen and a living room. Once the location was chosen, the monitor was removed from the aluminium can and the time noted. On the back of the monitor, the following information was recorded: time; monitor serial number; sampling date; and research identification number. Along with this information, temperature, relative humidity and carbon dioxide were recorded in the logbook. The monitor was affixed to the wall, at a height of 1.5 m, using a string drawn between two pieces of painters tape (Figure 3.9). Painters tape was used so that the homes of the volunteers would not be damaged. A height of 1.5 m was also used during the Canadian study (Otson et al., 1992b) and the study done in the Kanawha Valley (Cohen et al., 1989).

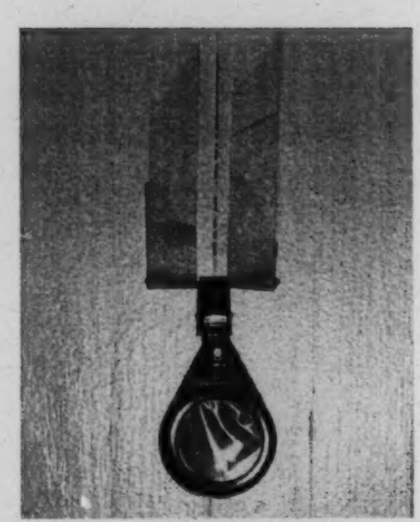

Figure 3.9 Monitor affixed to wall.

Once the sampler was placed inside, an additional sampler was placed outside following a similar procedure. For the fall sampling period, a 1.2 m stake was driven into the lawn from which the monitor could be hung. The stakes were placed near the front of the house away from driveways and under an overhang, if possible. Deployment of the samplers outside was done in the same manner as described above. The only exception is that temperature, relative humidity and carbon dioxide were not recorded. Temperature and relative humidity were obtained from Environment Canada.

For the winter sampling period, an alternate method for deploying the samplers outside was used. Instead of stakes, a 1.2 m stand was developed that could be placed in the snow and had its own shelter (Figure 3.10). Aluminium cans were attached to the middle post to house the monitors. It was necessary to shield the samplers to stop snow from collecting on the Teflon membrane and interfering with sampling.

Figure 3.10 Winter stand.

The samplers were collected 24 hours later, plus or minus a half-hour. To complete sampling the plastic ring and Teflon membrane were removed from the monitor and the closure cap placed on the monitor, ensuring both ports were firmly in place. The finish time was then recorded on the monitor and in the logbook, along with the temperature, relative humidity and carbon dioxide concentration. Lastly, the monitor was placed in its original can and sealed with Teflon tape.

Once the indoor monitor was collected, the *Household Activities* questionnaire was completed with the participant and the *Household Characteristics* questionnaire was collected. Lastly, the outdoor monitor was collected as described above. Sealed cans containing the indoor and outdoor monitors were then placed on ice in a cooler until they could be transported back to the lab. All monitors were transported to the lab at the end of the day and placed in a refrigerator at 4°C until extraction. Extraction was done within one week of collection.

3.5.1.1 Quality Assurance and Quality Control (QA/QC)

Approximately 10% of the monitors were used for quality assurance and quality control (QA/QC). Once a week sampling was done in triplicate, alternating between indoors and outdoors. Field blanks were also performed once a week on a pick-up day, alternating indoors and out. 3M recommends handling the monitor in the same manner as the sample monitors (3M, 1996a). Field blanks are prepared in the following manner:

1. Remove monitor from can.
2. Remove plastic ring and Teflon membrane and immediately replace with closure cap, ensuring both ports are sealed.
3. Record blank code, sampling date and time on monitor and in the logbook.
4. Place monitor in aluminium can and seal with Teflon tape.
5. Place can in cooler for transport back to the laboratory.

Chapter 4: Sample Analysis

4.1 VOC Selection

The VOCs to be sampled were determined based on the following selection criteria: industrial emission, health effects, amiability to sampling by the OVM 3500 and readily analysed by GC/MS. The first step in selecting which VOCs to sample for was creating a list of pollutants released by industry. This list was generated based on emissions reported to the 1995 National Pollutant Release Inventory (Environment Canada, 1999). The inventory was downloaded from Environment Canada's web page and then filtered for industries in the industrial corridor. The search criteria used was any facility between 100 Street, Edmonton and Sherwood Drive, in Sherwood Park and between 45 Avenue and 153 Avenue, Edmonton (Figure 4.1). The majority of facilities were between 50 Street and Highway 14X, and 92 Avenue and 137 Avenue. All VOCs emitted in this area were then recorded as potential VOCs to monitor.

Compounds were then added to this list based on a variety of other sources. The TEAM Study (Wallace, 1986) and the Canadian study (Fellin and Otson, 1993) were used to identify compounds generally found indoors. A draft report from Alberta Environmental Protection (Bates, 1996) identified VOCs that were measurable in the ambient environment. Lastly, the Clean Air Act (1990) (EPA, 1999) organic hazardous air pollutants and the Canadian Environmental Protection Act, Priority Substance List 1 (Health Canada, 1999) were also used. At this point approximately 50 potential compounds were identified for monitoring. These compounds were then screened for potential health effects. Compounds that were either released by industry or had potential health effects were given the highest priority for monitoring.

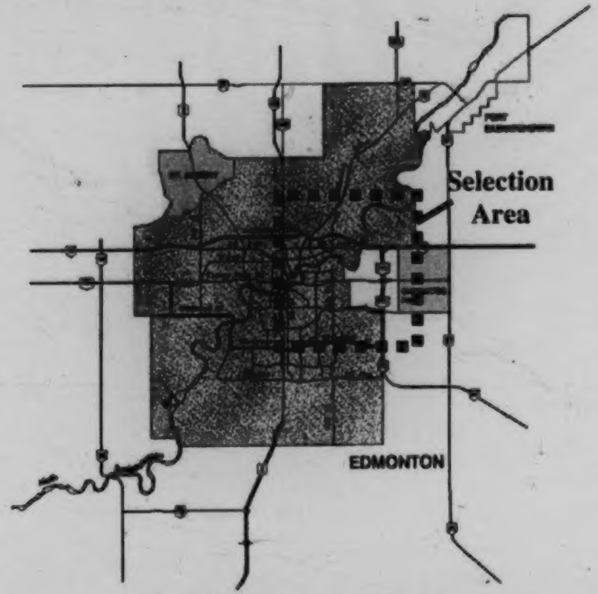

Figure 4.1 Map of industrial emissions selection area (Adapted from Alberta Infrastructure, 1999).

Once potential health effects were identified, it was important to determine which compounds were typically found indoors. The reason for this was to identify compounds that were released by industry but were not common indoors. It was hoped that these compounds would serve as indicators of industrial emissions infiltrating into homes in Sherwood Park. Lists from the TEAM Study and the Canadian study were used, as well as lists from summary reports on VOCs (Brooks and Davis, 1992; Otson and Fellin, 1992). From the final list of VOCs, only three compounds were found to be released by industry and not found indoors: cumene, methyl isobutyl ketone and tert-butyl alcohol. This does not mean that these compounds cannot be found indoors without an industrial source, only that they were not listed as typical indoor pollutants by the sources researched.

The next step was to identify which compounds could be collected by the OVM 3500 and analysed by GC/MS. Since some of the compounds were not amiable to the OVM and others were too difficult to analyse by GC/MS the list was reduced to 28 compounds (Table 4.1). The final list of 28 VOCs with the screening process is in Appendix 8.6. Also shown in the list are reported odour thresholds. VOCs with potential odours were identified in case any of the volunteers had observed certain odours during the sampling periods.

Table 4.1 VOCs analysed during study.

Volatile Organic Compound	Industrial Emission	Volatile Organic Compound	Industrial Emission
1,1,1 Trichloroethane		Ethylbenzene (benzene tetrahydride, 1,2,3,4-tetrahydrobenzene)	✓
1,1,2 Trichloroethane		Ethylene Dichloride (1,2 Dichloroethane)	
1,1,2,2-Tetrachloroethane		Hexachlorobutadiene	
1,1-Dichloroethane		1,3-Dichlorobenzene	
1,2,3-Trichloropropane		1,4-Dichlorobenzene	
1,2,4-Trimethylbenzene (mesitylene)	✓	Methyl isobutyl ketone (Hexone, 4-Methyl-2-pentanone)	✓
1,3,5-Trimethylbenzene		Naphthalene	✓
Acetone	✓	Styrene	✓
Benzene	✓	Tert-butyl alcohol (2-methyl-2-propanol, trimethyl carbinol, isobutanol)	✓
Bromoform		Tetrachloroethylene (Perchloroethylene, Tetrachloroethene)	✓
Carbon Tetrachloride		Toluene	✓
Chloroform		Trichloroethylene (Trichloroethene, ethylene trichloride, triclene)	
Chlorobenzene		(*m*+*p*) Xylene	✓
Cumene (isopropylbenzene)	✓	o-Xylene	✓

4.2 Desorption

Once the sorbent material has collected compounds from the air, the contaminants need to be extracted for analysis. Two methods used are solvent extraction and thermal desorption. Solvent extraction uses compounds like carbon disulphide and methanol to remove compounds from the sorbent material and put them in a liquid form. The advantage of solvent extraction is that only a portion of the solution is analysed, making replicate analysis possible, as well as future analysis (Keith, 1991). The main disadvantage stems from the amount of sample used. Since only a small portion of the sample is used the minimum levels of detection are higher than would be the case if the entire sample was used. To compensate for this it is recommended to collect larger volumes of sample (Keith, 1991).

Smaller volumes of air are required when thermal desorption is used because the entire sample is used. The disadvantages to thermal desorption is that no sample is left after the initial analysis and some of the analytes may decompose during pyrolysis (Keith, 1991).

4.2.1 Desorption Procedures

The samplers were prepared for analysis by extracting the compounds from the charcoal pad with carbon disulphide. Prior to extraction, the carbon disulphide needed to be purified due to the low concentrations being sampled and the relatively short sampling time. The carbon disulphide cleaning procedure was supplied by Philip Fellin (Conor Pacific, Toronto) through a personal communication (Fellin, 1998).

1. Thermally clean molecular sieve (type 13 x 8 – 12 mesh, $^1/_{16}$ - inch beads) for 3 hours at 250°C in a ultra high purity nitrogen atmosphere oven (Figure 4.2).
2. Fill a 50 mL Pyrex burette (63o mm x 10 mm) to within 50 mm of the top with clean molecular sieve.
3. Pass a 30 mL aliquot of CS_2 through the burette at a flow rate of approx. 2 mL/min.
4. Collect the CS_2 in a pre-cleaned jar and then filter a second time.
5. Repeat steps 3 and 4 for another 30 mL aliquot.
6. After 60 mL of CS_2 has been cleaned regenerate molecular sieve (step 1).

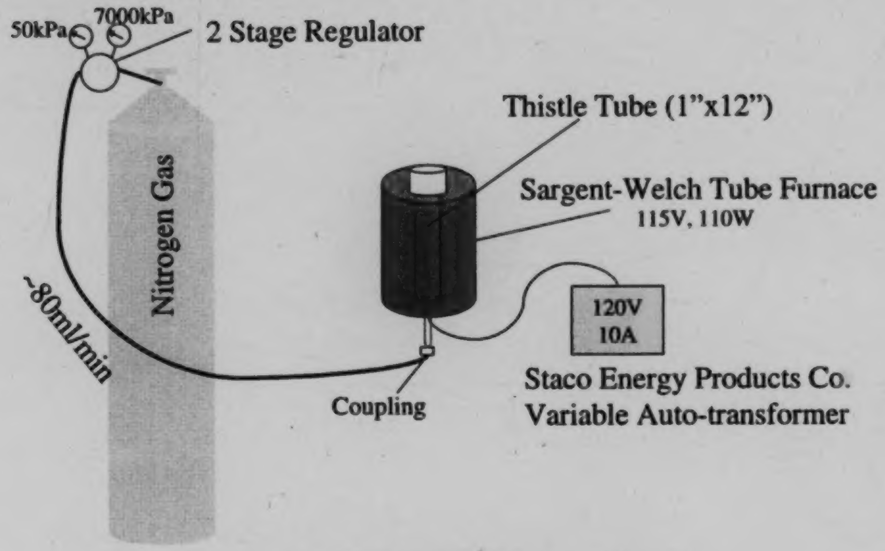
50kPa
7000kPa
2 Stage Regulator
Nitrogen Gas
Thistle Tube (1"x12")
Sargent-Welch Tube Furnace
115V, 110W
120V
10A
~80ml/min
Coupling
Staco Energy Products Co.
Variable Auto-transformer

Figure 4.2 Filter media conditioner.

Once enough carbon disulphide had been cleaned to complete a week's worth of monitoring the extractions began (Figure 4.4). Samplers were removed from the refrigerator and brought to room temperature. The monitors were then removed from the cans and inspected to ensure that the closure cap was secure and the plugs firmly closed (Figure 4.3). To extract the compounds 1.5 mL of carbon disulphide was injected into the centre port (the rim port was opened to allow venting). After injection, both ports were closed and the monitor was placed on a shaker table set at 125 rpm. After a half-hour both ports were opened and the decanting spout inserted into the rim port. The liquid was then transferred to a 2 mL autosampler vial and sealed. All vials were stored at -50°C until GC/MS analysis.

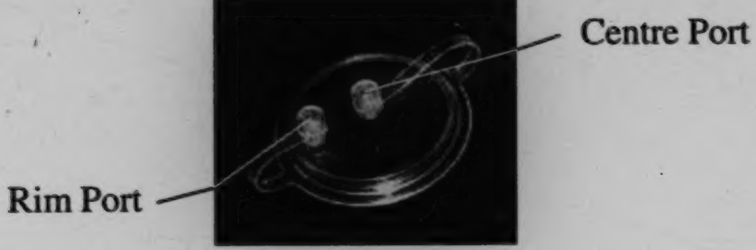

Figure 4.3: **Closure cap.**

1. Bring monitor to room temperature
2. Remove monitor from can and inspect closure cap
3. Inject 1.5 mL CS_2 into centre port with rim port open to allow venting
4. Let monitor stand for a ½ hour on a shaker table
5. Insert decanting spout and transfer to an autosampler vial

Figure 4.4 **Desorption procedure.**

4.2.1.1 Quality Assurance and Quality Control

To reduce potential sources of contamination, all glassware used during sample preparation was cleaned thoroughly and then baked at 180°C to remove VOCs.

The quality of the cleaned carbon disulphide was tested by putting 1.5 mL of cleaned and pre-cleaned carbon disulphide into autosampler vials for every set of extractions.

4.2.2 Desorption Efficiencies

Several different methods have been developed for determining the desorption efficiency (DE) of passive samplers: dynamic method; phase equilibrium method; and variations on injecting the liquid onto the charcoal. The dynamic method involves the adsorption of a substance from a standard air mixture (Krajewski et al., 1980). Phase equilibrium involves adding a known quantity of a compound to a volume of CS_2 and analysing the solution by gas chromatography. Charcoal is then added to the standard solution, which is at dry ice temperature. After the mixture reaches equilibrium at room temperature it is analysed by gas chromatography. Other methods involve injecting the compounds directly onto the charcoal or injecting a standard solution in CS_2. 3M developed a method for the OVM 3500, which is a combination of direct injection and the dynamic method. The procedure involves placing a piece of filter paper above the adsorbent and injecting a known amount of material onto the filter paper, in a sealed monitor. This creates a diffusion layer between the filter paper and the charcoal pad.

Krajewski et al. (1980) investigated the phase equilibrium method, the direct injection methods and the dynamic method and found that the amount of analyte did not affect the DE. The researchers also investigated phase equilibrium and direct injection methods relative to the dynamic method (reference method). It was found that the method involving direct injection of a standard solution in CS_2 was not statistically different from the reference method in most cases. In comparison, phase equilibrium resulted in higher desorption efficiencies than the dynamic method (Krajewski et al., 1980).

During a validation study of the OVM 3500 (Cohen et al., 1990) DEs were calculated according to 3M's procedures. Spikes were done at 5, 20 and 100 µg/badge, in duplicate. The analysis was done for five compounds (chloroform, benzene, heptane, tetrachloroethylene and *p*-dichlorobenzene) and the DEs ranged from 92% to 116% (Cohen et al., 1990). For the study done in the Kanawha Valley DEs were taken from 3M's literature, with the exception of four compounds that were not listed. DEs were calculated for 4-ethyltoluene, 1,2,4-trimethylbenzene, decane and 1,2,4-trichlorobenzene. The DEs ranged from 76% to 95% (Cohen et al., 1989).

For this study, desorption efficiencies were taken from 3M's literature.

4.3 Sample Quantification

In order to determine which compounds are present in a sample and in what quantity, the VOCs need to be separated and detected.

4.3.1 Separation

Chromatography is the process whereby chemicals are partitioned between a mobile phase and a stationary phase. One type of chromatography is Gas Chromatography (GC). Compounds are separated by GC based on their volatility and their interaction with a stationary phase (NAS, 1991). The mobile phase for GC is a gas, while the stationary phase can vary from molecular sieves to liquids. It is the mobile phase used in GC work that makes it particularly useful for analysis of air samples.

One of the advantages of gas chromatographs is that they can be used with several different detection devices. This allows the machine to be adapted for several different analyses. Another advantage is that they can analyse a variety of compounds. Gas chromatographs also have the potential to be fully automated. This feature allows the instrument to run unattended; thus reducing costs and increasing the number of samples analysed. Liquid auto-injectors are another automated feature that increases the usefulness of gas chromatography (NAS, 1991). Sample extracts desorbed from a passive monitor, such as those used in this study can be injected straight into the gas chromatograph for analysis.

The ability of GC to differentiate between a variety of compounds leads to one of its disadvantages. The separation process that yields its high specificity is slow. As a result samples cannot be continuously analysed. Another disadvantage to GC is that it is not necessarily comprehensive. Compounds have been known to decompose in the gas chromatogram as well as react with the stationary phase or the column material. If a compound decomposes on the column and forms another compound a misleading result may be obtained (NAS, 1991).

4.3.2 Detection

Detection is the process whereby an analyte is converted to a measurable signal which gives the chemical identity or the amount (NAS, 1991). One of the most commonly used detection methods for organic compounds is Mass Spectrometry (MS). Within a mass spectrometer, compounds are broken down to molecular ions or molecular ion fragments. The ion being monitored is then chosen based upon its mass.

Mass spectrometers are highly sensitive and can detect any compound that can pass through a gas chromatograph. This high sensitivity is a result of the discriminating power of the mass spectrometer; it has the power to reject everything but the mass of interest by removing background signals.

4.3.3 Gas Chromatography – Mass Spectrometry

The combination of gas chromatography with mass spectrometry (GC/MS) provides a very useful and highly sensitive tool for analysing air samples. GC/MS has been demonstrated to have high sensitivity, be highly selective and be fairly comprehensive (NAS, 1991). The GC/MS combination was chosen for this study for these reasons. In addition, GC/MS is able to detect compounds at the low levels typically found in the indoor and ambient environments. As well, the selectivity and comprehensiveness was sufficient for the determination of the compounds of interest.

4.4 Analysis Procedures

A Varian 3800 Gas Chromatograph and Saturn 2000 Ion Trap Mass Spectrometer (Varian Canada Inc., Mississauga, ON) was used to analyse the CS_2 extracts. Sample analysis was initiated by injecting 2.0 μL of CS_2 extract into the GC/MS. The individual compounds were typically identified based on their mass spectra. However, some of the compounds had to be identified based on their retention times as certain compounds had similar spectra. Quantification of the amount of a particular VOC in the extracts was done through the use of an external calibration curve. An external standard calibration curve plots the amount of analyte (based on concentration of standard) versus the detector response (peak area). Standards with concentrations in the linear range of the detector were analysed and plotted. The response is said to be linear when the peak area is proportional to the amount (Harris, 1991).

The sensitivity for each compound was determined every run to account for fluctuations in noise. Sensitivity is defined as the smallest amount detectable of any compound (Rood, 1999). Signal to noise ratios were used as a measure of sensitivity. In order for a response to be considered detectable the signal to noise ratio had to be greater than 3, which means the peak height is three times the noise. Method detection limits (MDLs) for the compounds analysed were based on averaging three times the noise level of seven random samples.

To ensure the stability of the response, independent check samples were analysed every ten samples. In addition, instrumental and solvent blanks were also run. The VOC Instrumental Method supplied by the research technician (Mr. Jeff Rose, Department of Public Health Sciences, University of Alberta, Edmonton) is given in Appendix 8.7.

GC/MS provides an amount of a compound collected per badge. This amount is converted to a time weighted average based on the equation recommended by 3M (1998). Appendix 8.8 describes the calculation procedure and assumptions made.

Chapter 5: Results & Discussion

Sampling procedures outlined previously were followed for all homes over the course of the study. All samplers were left exposed for approximately 24 hours and then returned to the lab for extraction and analysis. The average exposure time for a sampler was 24 hours. The longest sampling time was 24.5 hours and the shortest was 23.7 hours.

All samples were extracted within one week of collection and stored in a freezer. Unfortunately, the samples were not all analysed in a timely fashion. The samples were analysed as a batch following the completion of sample collection in February. Analysis by GC/MS was done starting in late February (Feb. 21, 1999) and finished at the beginning of April (April 7, 1999).

Due to the significant delay in the analysis of the fall samples, it is felt that sample loss or contamination may have affected the fall results. For this reason the fall and winter data sets have been analysed separately and an analysis of seasonal effects was not investigated.

5.1 Quality Assurance/Quality Control (QA/QC)

Several different approaches were taken to address quality assurance and quality control. Trip blanks and replicates were collected in the field. Analytical detection limits were determined experimentally and only compounds with an appropriate number of samples above detection were used for interpretation.

5.1.1 Percent Below Detection Analysis

A total of 28 compounds were analysed initially by GC/MS. Before any data manipulation was started the compounds were screened based on an USEPA standard for handling values below detection limits. If more than 25% of the data is below the limit of detection no statistics should be calculated for the data (Nehls, 1973). Initially, the percent below detection was calculated for the fall and winter data sets combined (Second column of Table 5.1). This initial screening was done prior to removing background contamination as determined by trip blanks and the results are presented in Table 5.1. This screening procedure reduced the number of available compounds to 15. The initial screening was done to reduce the amount of unnecessary data manipulation.

For the remaining 15 compounds air concentrations were calculated taking into account background contamination as determined by the trip blanks. Once the air concentrations were determined the screening procedure was repeated for the fall and winter data sets separately. The percent below the limit of detection for the fall and winter data sets are presented in the third and fourth columns of Table 5.1, respectively. Acetone and tert-butyl alcohol were not analysed in fall samples due to time restrictions. The remaining eight compounds for the fall data set are 1,1,1-trichloroethane, carbon tetrachloride, toluene, tetrachloroethylene, ethylbenzene, (*m+p*) xylene, *o*-xylene, and 1,2,4-trimethlybenzene. Tetrachloroethylene had 26% of the samples below detection; however it was included in the analysis because it is included in the winter analysis. Of the remaining compounds only 1,1,1-trichloroethane and carbon tetrachloride did not have known industrial emission sources.

Nine compounds remained for the winter data set: 1,1,1-trichloroethane, carbon tetrachloride, benzene, tetrachloroethylene, ethylbenzene, (*m+p*) xylene, *o*-xylene, and 1,2,4-trimethlybenzene, and 1,3,5-trimethylbenzene. The compounds analysed for the fall and winter phases were similar except toluene, which was excluded from the winter data set and benzene and 1,3,5-trimethylbenzene, which were analysed in the winter data set and not the fall.

Table 5.1 Percent of samples below detection limits (BDL).

	Fall & Winter % BDL	Fall % BDL	Winter % BDL
Number of Samples	***245***	***121***	***124***
1,1-Dichloroethane	100%		
Chloroform	6%	38%	30%
1,1,1-Trichloroethane	0%	0%	2%
Carbon Tetrachloride	5%	6%	5%
Benzene	25%	60%	10%
Trichloroethylene	37%		
Toluene	0%	21%	44%
1,1,2-Trichloroethane	99%		
Tetrachloroethylene	19%	26%	23%
Chlorobenzene	7%	57%	68%
Ethylbenzene	0%	6%	8%
(*m*+*p*) xylene	0%	4%	7%
o-xylene	1%	3%	7%
Styrene	53%		
Bromoform	98%		
isopropylbenzene	74%		
1,1,2,2-Tetrachloropropane	100%		
1,2,3-Trichloropropane	98%		
Hexachlorobutadiene	100%		
Naphthalene	11%	45%	48%
1,2-Dichloroethane	81%		
1,3,5-Trimethylbenzene	3%	99%	11%
1,2,4-Trimethylbenzene	0%	0%	15%
1,3-Dichlorobenzene	98%		
1,4-Dichlorobenzene	51%		
Acetone	5%		89%
tert-Butyl Alcohol	20%		60%
Methyl Isobutyl Ketone	45%		

Compounds used for statistical analysis.

5.1.2 Analysis of Trip Blanks

Trip blanks were collected once a week during the fall and winter sampling periods. Seven blanks were collected in the fall and six in the winter. Table 5.2 summarises background contamination as determined by the analysis of trip blanks. The reported concentrations are in ng of compound per mL of carbon disulphide. Background contamination was only determined for those compounds remaining after the initial screening (<25% of the samples BDL). Carbon tetrachloride was the only compound not detected in the trip blanks. Trip blanks were handled in the same manner as all of the samples and therefore they would account for any potential contamination from the manufacturers, transport, storage, and laboratory conditions as well as carbon disulphide quality. Background contamination, as determined by the trip blanks, was subtracted from individual sample amounts prior to calculating air concentrations.

Table 5.2 Average background contamination of monitors.

	Amount (ng/mL)	
	Fall (n=7)	**Winter (n=6)**
Chloroform	32	39
1,1,1-Trichloroethane	6	14
Carbon Tetrachloride	BDL	BDL
Benzene	100	42
Toluene	200	430
Tetrachloroethylene	9	20
Chlorobenzene	7	6
Ethylbenzene	12	17
(*m+p*) xylene	47	51
***o*-xylene**	18	21
Naphthalene	14	12
1,3,5-Trimethylbenzene	1000	14
1,2,4-Trimethylbenzene	BDL	50
Acetone	---	23
tert-Butyl Alcohol	---	11

5.1.3 Precision

To estimate the precision of the monitors, samples were taken in triplicate once a week. The triplicates were alternated between indoor and outdoor sampling locations. A total of seven sets of triplicates were taken in the fall and six sets were collected during the winter sampling period. To estimate precision intraclass correlation coefficients were calculated. Lee et al. (1995) found intraclass correlation coefficients (r_I) to be an appropriate measure of the precision of passive samplers. Table 5.3 summarises the intraclass correlation coefficients for the fall sampling period. With the exception of carbon tetrachloride and toluene the fall replicates showed high precision. The intraclass correlation coefficients for carbon tetrachloride and toluene have greater uncertainty associated with them as can be seen from the large confidence interval.

Table 5.3 Precision as determined from fall replicates.

n = 7	r_I	Confidence Interval
1,1,1-Trichloroethane	0.98	0.99 $\leq r_I \leq$ 0.91
Carbon Tetrachloride	0.67	0.91 $\leq r_I \leq$ 0.13
Toluene	0.82	0.95 $\leq r_I \leq$ 0.44
Tetrachloroethylene	0.95	0.99 $\leq r_I \leq$ 0.80
Ethylbenzene	0.98	1.00 $\leq r_I \leq$ 0.93
(*m+p*) xylene	0.98	1.00 $\leq r_I \leq$ 0.93
***o*-xylene**	0.97	0.99 $\leq r_I \leq$ 0.91
1,2,4-Trimethylbenzene	0.98	0.99 $\leq r_I \leq$ 0.91

Winter replicates showed significantly less precision than fall samples. The only exception was 1,1,1-trichloroethane with an interclass correlation coefficient of 0.93. Table 5.4 summarises correlation coefficients for winter replicates. One measurement was removed from the precision calculation for 1,3,5-trimethylbenzene as it was determined that it should be discarded based on the Q-test (Harris, 1991). Similar to the fall replicates, carbon tetrachloride showed the poorest precision. In an attempt to understand why winter replicates showed poor precision in comparison to the fall replicates, intraclass correlation coefficients were calculated for the indoor and outdoor replicates separately. Table 5.5 summarises these intraclass correlation coefficients. The bias of these coefficients is increased relative to the bias of the coefficients calculated using the entire set due to the small sample sizes (n=3). However, it does show that the precision of the outdoor samples is generally less than for the indoor samples, with the exception of carbon tetrachloride and benzene. The lower precision of the winter outdoor samples could be a result of low temperatures observed on the replicate sampling days. The daily average temperatures ranged from -2°C to -18°C when the winter outdoor replicates were taken. Moreover, the outdoor winter samplers were housed in cans to protect them from snowfall; however the cans may have restricted airflow and affected the sampler efficiency.

Table 5.4 Precision as determined from winter replicates.

n = 6	r_I	Confidence Interval
1,1,1-Trichloroethane	0.93	0.98 $\le r_I \le$ 0.71
Carbon Tetrachloride	0.26	0.79 $\le r_I \le$ -0.44
Benzene	0.31	0.81 $\le r_I \le$ -0.40
Tetrachloroethylene	0.33	0.81 $\le r_I \le$ -0.38
Ethylbenzene	0.67	0.92 $\le r_I \le$ 0.07
(*m+p*) xylene	0.54	0.89 $\le r_I \le$ -0.13
***o*-xylene**	0.46	0.86 $\le r_I \le$ -0.24
1,3,5-Trimethylbenzene	0.64	0.91 $\le r_I \le$ 0.02*
1,2,4-Trimethylbenzene	0.54	0.89 $\le r_I \le$ -0.14

* One replicate set is only a duplicate

Table 5.5 **Comparison of indoor and outdoor intraclass correlation coefficients.**

n = 3	Outdoor r_i	Indoor r_i
1,1,1-Trichloroethane	0.25	0.91
Carbon Tetrachloride	0.43	-0.02
Benzene	0.10	-0.04
Tetrachloroethylene	-0.14	0.66
Ethylbenzene	0.16	0.73
(*m+p*) xylene	0.11	0.65
***o*-xylene**	0.19	0.90
1,3,5-Trimethylbenzene	0.56	0.77
1,2,4-Trimethylbenzene	0.44	0.76

5.1.4 Analytical Detection Limits

Actual detection limits vary from sample to sample because detection was based on a signal to noise ratio. The method detection limit (MDL) for each sample is equal to three times the noise and the reported MDLs are an average of seven random sample MDLs. Table 5.6 summarises the MDLs, in ng/mL CS_2 extract and μg/m^3 volumetric air sample, for the compounds remaining after the analysis of percent below detection. The analytical detection limit was converted to an air concentration by assuming an exposure time of 24 hours. MDLs ranged from 0.2 to 1 μg/m^3 with benzene having the highest MDL. The average MDL for the compounds analysed is 0.5 μg/m^3.

Table 5.6 **Method detection limits.**

	MDL (ng/mL)	MDL (μg/m^3)
1,1,1-Trichloroethane	7	0.2
Carbon Tetrachloride	10	0.4
Benzene	41	1
Toluene	6	0.2
Tetrachloroethylene	14	0.5
Ethylbenzene	5	0.2
(*m+p*) xylene	6	0.2
***o*-xylene**	8	0.3
1,3,5-Trimethylbenzene	6	0.2
1,2,4-Trimethylbenzene	5	0.2

5.2 Fall Sampling

Fall samples were collected from September 21 to November 6 of 1998, immediately following the recruitment process. A total of 159 samples were collected and analysed, including replicates and blanks.

5.2.1 Fall Meteorological Conditions

Ambient meteorological conditions were obtained from Environment Canada for both the fall and winter sampling periods. Measurements were recorded at the Edmonton municipal airport, which is approximately half way between St. Albert and Sherwood Park. Meteorological data was obtained for temperature, relative humidity, pressure, wind speed, wind direction and precipitation. Table 5.7 summarises the meteorological conditions of the fall sampling period. The average daily temperature was 6.5°C and the average daily relative humidity was 77%. The daily variations in temperature and relative humidity are shown in Figure 5.1 and Figure 5.2. From Figure 5.1 it can be seen that temperature was highly variable over the study period ranging from +14°C to −1.4°C. Relative humidity was also variable but not as significant as was observed for temperature.

Table 5.7 Average daily fall conditions.

	Average	Maximum	Minimum
Temperature (°C)	6.5	14	-1.4
Relative Humidity (%)	77	97	56
Pressure (KPa)	9364	9466	9248
Wind Speed (km/hr)	12	23	3.5

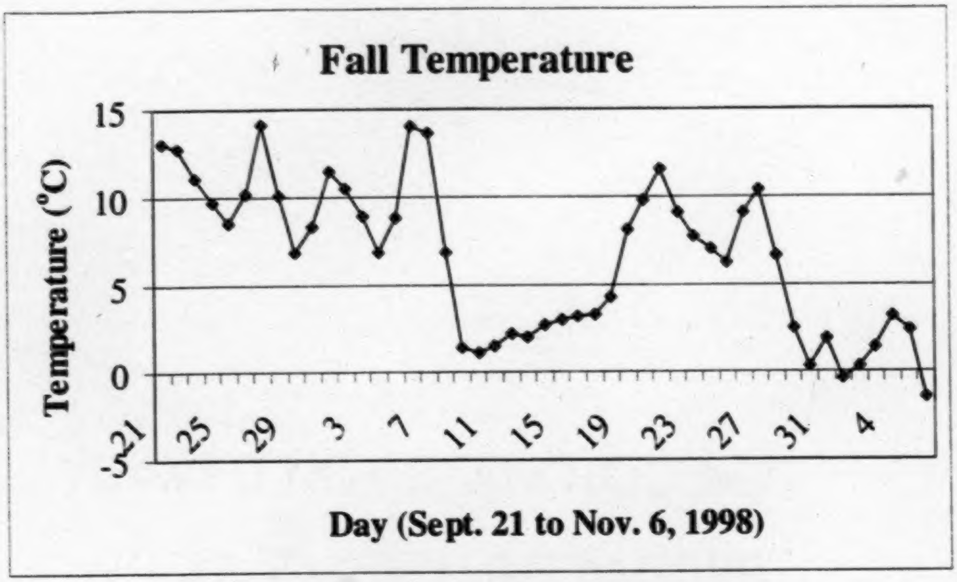

Figure 5.1 Fall average daily temperatures.

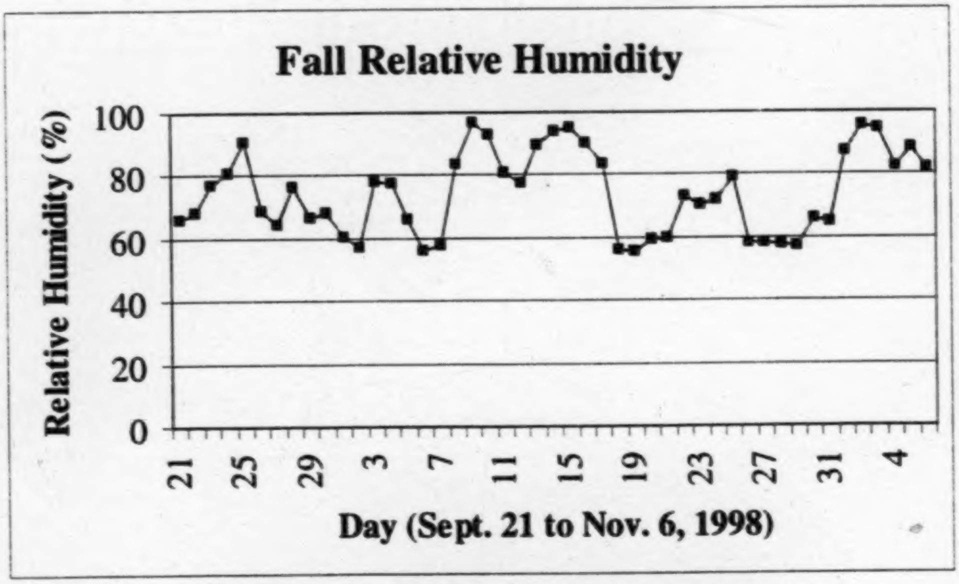

Figure 5.2 Average daily fall relative humidity.

Wind direction was plotted to examine wind direction frequencies relative to the locations of Sherwood Park and St. Albert (Figure 5.3). The wind blew from a southerly (SE to SW) direction approximately 40% of the time. For Sherwood Park to experience the strongest impacts from the industrial corridor, the wind would need to blow from a west/north-west direction, and this occurred 16% of the time.

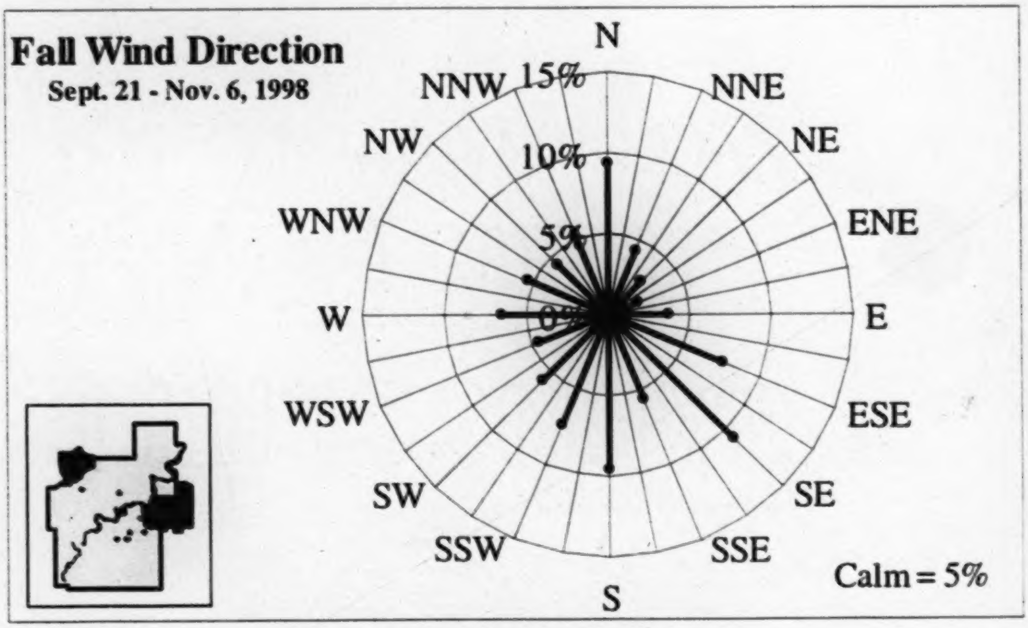

Figure 5.3 Fall wind direction frequency.

Over the course of the fall sampling period precipitation conditions also varied. Conditions varied between rain, snow and no precipitation. The most rain received in one day was 8 mm and occurred on September 25, 1998. The maximum snowfall recorded was 13 cm and occurred on October 9, 1998. Total precipitation for the sampling period equalled 46 mm. Precipitation conditions over the fall sampling period are summarised in Table 5.8.

Table 5.8 **Fall precipitation conditions.**

	Rain (mm)	Snowfall (cm)	Total Precipitation (mm)
Total	27	20	46
Maximum	8	13	16

5.2.2 Indoor Conditions During Fall Sampling Period

Measurements of temperature, relative humidity and carbon dioxide were made in the homes sampled. Table 5.9 summarises the average conditions recorded in the participant's homes. All measurements were within the operating conditions of the monitor. From the carbon dioxide measurements it was observed that the majority of the homes had adequate ventilation.

Table 5.9 **Fall indoor sampling conditions.**

	Temperature (°C)	Relative Humidity (%)	Carbon Dioxide (ppm)
Average	20	49	773
Maximum	25	75	1782
Minimum	15	30	433

5.2.3 Results of Fall Sampling Period

The fall sampling results include 29 indoor and 29 outdoor samples for St. Albert and 32 indoor and 31 outdoor samples for Sherwood Park. The results from some of the monitors could not be evaluated due to excessive sample loss from the autosampler vials and some of the results were lost due to corrupted computer files. Eight compounds were analysed in the fall data set: 1,1,1-trichloroethane, carbon tetrachloride, toluene, tetrachloroethylene, ethylbenzene, (*m+p*) xylene, *o*-xylene, and 1,2,4-trimethlybenzene

Table 5.10 summarises descriptive statistics for St. Albert and Sherwood Park. The two highest concentrations were recorded indoors and are for (*m*+*p*) xylene (630 μg/m^3) and 1,2,4-trimethylbenzene (450 μg/m^3) in St. Albert. The two highest indoor mean concentrations are for (*m*+*p*) xylene in St. Albert (32 μg/m^3) and toluene in Sherwood Park (20 μg/m^3). The highest mean concentrations observed outdoors are also toluene (9.6 μg/m^3) and (*m*+*p*) xylene (5.2 μg/m^3) and are from St. Albert.

It can be seen from Table 5.10 that indoor levels are highly variable in comparison to outdoor levels, in both Sherwood Park and St. Albert as determined by the standard deviations. This suggests that the outdoor samples were influenced by similar conditions within and surrounding the communities. The high variability of the indoor samples suggests an influence of localised indoor sources rather than the ambient environment.

Table 5.10 Descriptive summary statistics for fall air sampling (μg/m^3).

	Indoor							
	St. Albert (n = 29)				**Sherwood Park (n = 32)**			
	Mean	**Median**	**Std Dev**	**Max**	**Mean**	**Median**	**Std Dev**	**Max**
1,1,1-Trichlorethane	9.5	1.3	30	160	3.4	2.1	3.4	15
Carbon Tetrachloride	1.0	1.0	0.4	2.6	0.9	0.9	0.4	1.7
Toluene	16	9.7	14	55	20	14	16	60
Tetrachloroethylene	3.8	1.0	8.7	46	3	1.1	7.0	40
Ethylbenzene	9.4	2.5	34	190	5.1	2.9	6.6	34
(m+p) Xylene	32	8.2	120	630	15	9.5	16	78
o-Xylene	11	3.0	41	220	5.0	3.3	4.8	22
1,2,4-Trimethylbenzene	21	3.7	83	450	6.6	4.9	6.4	29

	Outdoor							
	St. Albert (n = 29)				**Sherwood Park (n = 31)**			
	Mean	**Median**	**Std Dev**	**Max**	**Mean**	**Median**	**Std Dev**	**Max**
1,1,1-Trichlorethane	0.7	0.6	0.3	1.6	0.7	0.6	0.5	3.0
Carbon Tetrachloride	1.0	1.0	0.3	1.5	0.9	1.0	0.3	1.5
Toluene	9.6	4.2	16	82	4.1	1.3	6.4	21
Tetrachloroethylene	0.7	0.4	0.7	2.9	0.8	0.4	1.4	7.5
Ethylbenzene	1.5	0.8	1.4	5.4	0.8	0.6	0.9	3.4
(m+p) Xylene	5.2	3.1	5.1	19	3.0	1.8	3.4	13
o-Xylene	1.9	1.0	1.9	6.5	1.1	0.6	1.2	1.6
1,2,4-Trimethylbenzene	2.7	1.6	2.3	10	2.6	1.3	4.4	25

5.3 Winter Sampling

Winter samples were collected from January 11 to February 13 of 1999. A total of 156 samples were collected and analysed, including replicates and blanks.

5.3.1 Meteorological Conditions

Average daily conditions for the winter sampling period are summarised in Table 5.11. The average daily temperature was -9.8°C and the average daily relative humidity was 77%. The daily variations of winter temperature and relative humidity are shown in

Figure 5.4 and

Figure **5.5**. Similar to the fall sampling period, it can be seen from

Figure 5.4 that temperature was highly variable over the winter study period ranging from +1°C to -22°C. Relative humidity was also variable but the variation was not as significant as for temperature.

Table 5.11 Winter average daily conditions.

	Average	Maximum	Minimum
Temperature (°C)	-9.8	0.7	-22.0
Relative Humidity (%)	77	91	62
Pressure (KPa)	9271	9465	9087
Wind Speed (km/hr)	10.6	17.9	5.6

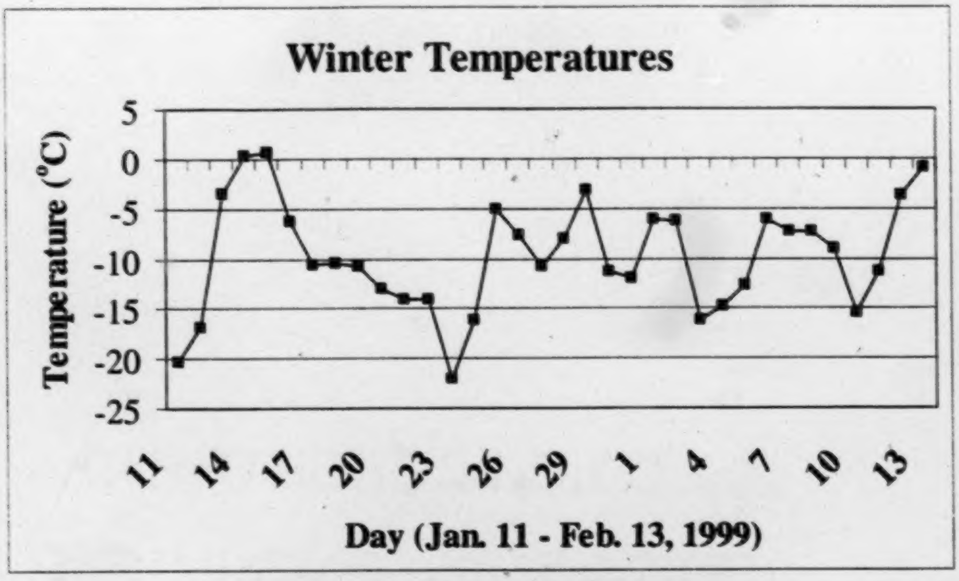

Figure 5.4 Average daily temperatures.

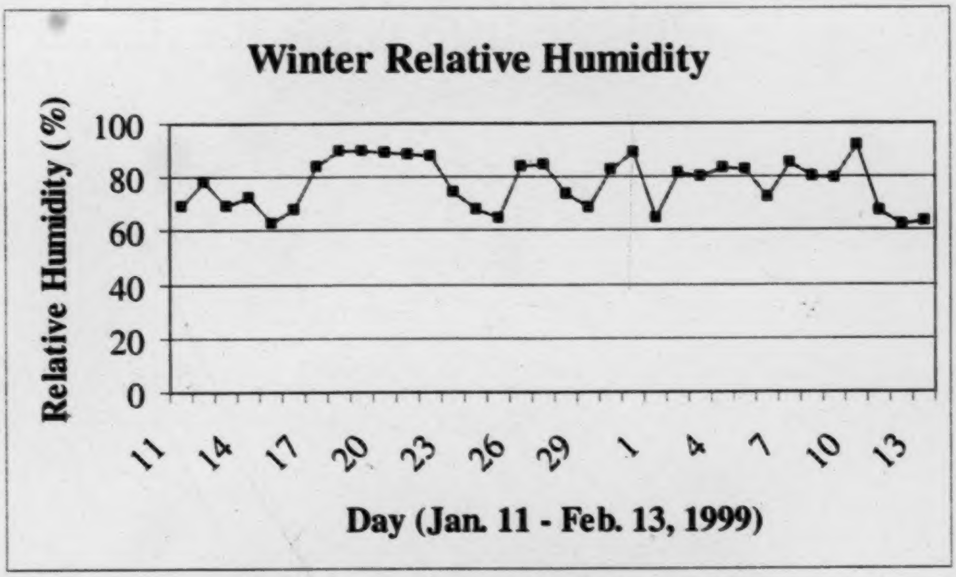

Figure 5.5 Average daily relative humidity.

Figure 5.6 is the wind direction plot for the winter sampling period. The wind blew from a southerly (SE to SW) direction approximately 40% of the time. This frequency was observed in the fall sampling period as well. The wind blew from a west/north-west direction only 16% of the time.

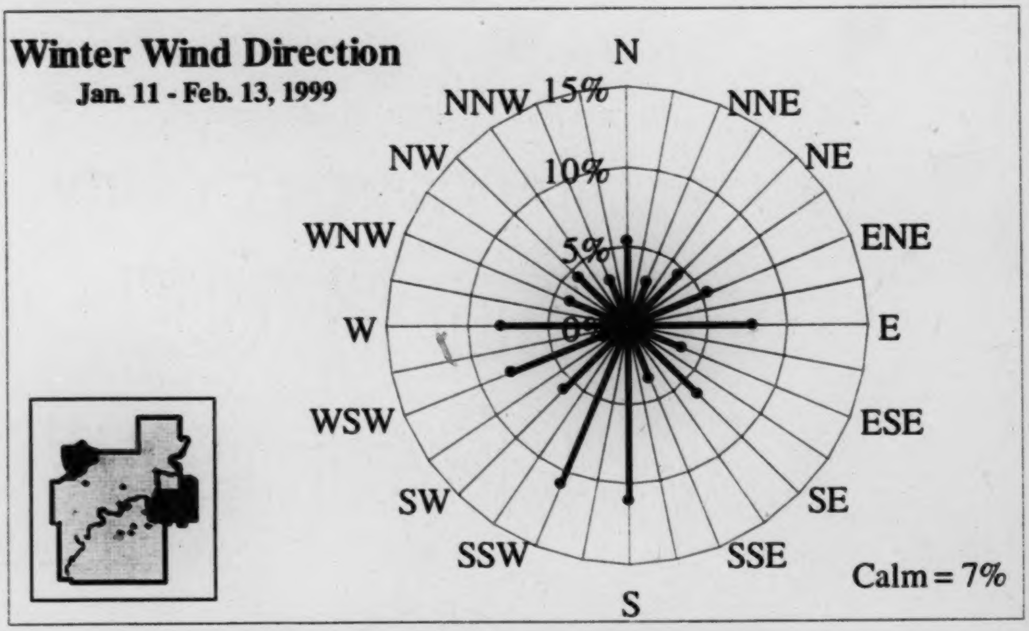

Figure 5.6 **Winter wind direction frequency.**

Over the course of the winter sampling period precipitation conditions also varied. Conditions varied from heavy snowfall to no precipitation. The maximum snowfall recorded was 12 cm and occurred on January 11. Total snowfall for the sampling period equalled 41 cm and total precipitation equalled 27 mm. Precipitation conditions are summarised in Table 5.12.

Table 5.12 **Winter precipitation conditions.**

	Snowfall (cm)	**Total Precipitation** (mm)
Total	41	27
Maximum	12	7.8

5.3.2 Indoor Sampling Conditions

Table 5.13 summarises the conditions recorded in the participant's homes during the winter sampling period. All measurements were within the operating conditions of the monitor. Temperature and carbon dioxide measurements were similar to what was recorded during the fall period. However, relative humidity decreased inside the homes for the winter sampling period.

Table 5.13 Indoor sampling conditions.

	Temperature (°C)	Relative Humidity (%)	Carbon Dioxide (ppm)
Average	18	34	790
Maximum	22	60	1713
Minimum	15	16	452

5.3.3 Results of Winter Sampling

The winter sampling results include 30 indoor and outdoor samples for St. Albert and 32 indoor and outdoor samples for Sherwood Park. Nine compounds were analysed in the winter data set: 1,1,1-Trichloroethane, Carbon Tetrachloride, Benzene, Tetrachloroethylene, Ethylbenzene, (*m+p*) xylene, *o*-xylene, 1,3,5-Trimethlybenzene, and 1,2,4-Trimethlybenzene.

Table 5.14 summarises descriptive statistics for St. Albert and Sherwood Park. The two highest concentrations were recorded indoors and are for (*m+p*) xylene (140 μg/m^3) in St. Albert and tetrachloroethylene (290 μg/m^3) in Sherwood Park. Tetrachloroethylene (10 μg/m^3) in Sherwood Park and (*m+p*) xylene (14 μg/m^3) in St. Albert had the highest indoor mean concentrations. In comparison the highest mean concentrations outdoors are from St. Albert and are for benzene (2.1 μg/m^3) and (*m*+*p*) xylene (3.6 μg/m^3).

Similar to the fall, indoor levels are highly variable in comparison to outdoor levels in both Sherwood Park and St. Albert.

Table 5.14 Descriptive summary statistics for winter air sampling (μg/m^3).

	Indoor							
	St. Albert (n = 30)				Sherwood Park (n = 32)			
	Mean	Median	Std Dev	Max	Mean	Median	Std Dev	Max
1,1,1-Trichlorethane	7.0	1.1	14	55	3.3	1.3	4.4	19
Carbon Tetrachloride	1.0	0.9	0.5	2.2	0.9	0.8	0.5	2.2
Benzene	3.4	3.3	2.3	12	3.7	2.9	3.4	18
Tetrachloroethylene	2.4	0.8	4.0	21	10	0.7	52	290
Ethylbenzene	3.5	1.8	6.4	35	2.1	1.4	2.2	11
(m+p) Xylene	14	7.4	26	140	7.9	5.7	9.0	45
o-Xylene	5.4	2.8	8.9	45	3.0	2.1	3.8	22
1,3,5-Trimethylbenzene	2.0	0.9	4.5	25	0.9	0.6	1.2	5.3
1,2,4-Trimethylbenzene	7.5	3.2	16	89	3.4	2.4	4.1	19
	Outdoor							
	St. Albert (n = 30)				Sherwood Park (n = 32)			
	Mean	Median	Std Dev	Max	Mean	Median	Std Dev	Max
1,1,1-Trichlorethane	0.5	0.3	0.4	2.2	0.4	0.3	0.3	1.4
Carbon Tetrachloride	0.9	0.8	0.5	2.5	1.0	0.8	1.2	7.2
Benzene	2.1	1.6	1.7	5.8	1.7	1.2	1.4	6.7
Tetrachloroethylene	0.5	0.3	0.5	2.1	0.4	0.3	0.3	1.5
Ethylbenzene	1.3	1.1	1.4	5.4	0.5	0.2	0.8	4.5
(m+p) Xylene	3.6	3.4	3.3	14	1.4	0.9	1.4	5.4
o-Xylene	1.5	1.2	1.3	5.1	0.6	0.5	0.6	3.2
1,3,5-Trimethylbenzene	0.4	0.3	0.4	1.4	0.2	0.1	0.2	0.9
1,2,4-Trimethylbenzene	1.5	1.1	1.5	4.7	0.7	0.4	0.9	3.4

5.4 Comparison of Results to Similar Studies

When the data collected in Sherwood Park and St. Albert are compared with studies done in Canada, Germany and the United States, it becomes apparent that the indoor concentrations are similar to those observed elsewhere, considering the large variability typically associated with indoor concentrations. Table 5.15 summarises the indoor results of this study along with some of those done in the United States, Germany and Canada. The values reported are medians with the exception of the results from the

Canadian study, which are averages. The most significant difference observed is between the levels of 1,1,1-trichloroethane recorded in Sherwood Park and St. Albert relative to those reported for the United States. The concentrations observed in the United States are significantly higher than those observed in this study.

The values reported from the study done in the Kanawha Valley are generally similar to the levels observed in Sherwood Park and St. Albert. This is a significant observation as the two studies were investigating similar issues. Similar to Sherwood Park, the Kanawha Valley is in a highly industrialised area and the researchers were investigating the potential impact of the local chemical industry on human exposure. (Cohen et al., 1989). The two studies also used the same passive monitors. In comparison, the TEAM studies and the German study were conducted using active samplers (Gebefuegi et al, 1995 & Hartwell et al., 1987b).

Table 5.15 Indoor median concentrations (µg/m^3) (Cohen et al., 1989; Gebefuegi, et al., 1995; Hartwell et al., 1987b; & Otson et al., 1994).

	St. Albert		Sherwood Park		Germany[1]	Canadian[2]
	Fall	Winter	Fall	Winter		
1,1,1-Trichlorethane	1.3	1.1	2.1	1.3		
Carbon Tetrachloride	1.0	0.9	0.9	0.8		
Toluene	9.7		14		10.2	41
Benzene		3.3		2.9	1.6	5
Tetrachloroethylene	1.0	0.8	1.1	0.7		3
Ethylbenzene	2.5	1.8	2.9	1.4	1.0	8
(*m*+*p*) Xylene	8.2	7.4	9.5	5.7	3.4	20
o-Xylene	3.0	2.8	3.3	2.1	1.1	6
1,3,5-Trimethylbenzene		0.9		0.6		3
1,2,4-Trimethylbenzene	3.7	3.2	4.9	2.4		12

	Kanawha Valley[2]	Night-time Personal Air Concentrations			
		New Jersey[3]	California[4]	Greensboro[5]	Devils Lake[7]
1,1,1-Trichlorethane		12	12.	26	37
Carbon Tetrachloride	3.3				
Toluene					
Benzene	2.1	10	8.5	11	---
Tetrachloroethylene	1.3	5.9	4.6	2.8	4.4
Ethylbenzene	2.7	5.0	4.2	2.2	2.7
(*m*+*p*) Xylene	7.3	13	14	6.4	8.4
o-Xylene	2.6	5.5	5.4	3.7	3.5
1,3,5-Trimethylbenzene					
1,2,4-Trimethylbenzene					

[1] Daytime sampling in Munich, Germany (n = 52).

[2] Mean concentrations from 24 hour samples collected across Canada (n = 757).

[3] 3 week samples collected in Kanawha Valley, West Virginia (n = 32)

[4] Combination of summer and winter 12 hr overnight samples in Bayonne and Elizabeth, New Jersey (n = 199-205).

[5] Combination of spring and winter 12 hr overnight samples in Los Angeles and spring in Antioch and Pittsburg, California (n = 234-235).

[6] 12 hr overnight samples in Greensboro, North Carolina (n= 24).

[7] 12 hr overnight samples in Devils Lake, North Dakota (n = 23).

Table 5.16 summarises outdoor median results of this study along with other ambient measurements. Values reported for the Strathcona industrial corridor and downtown Edmonton are median concentrations for a three year sampling period, with samples collected every sixth day for 24 hours. When the outdoor median concentrations for Sherwood Park and St. Albert are compared to those reported for downtown Edmonton and the Strathcona industrial corridor it can be seen that the concentrations are fairly similar. The greatest difference is between toluene and benzene concentrations. The median benzene and toluene concentrations observed in Sherwood Park and St. Albert are less than those found downtown.

The outdoor median concentrations observed in Sherwood Park and St. Albert were also similar to those recorded in the Kanawha Valley of West Virginia; Greensboro, North Carolina; and Munich, Germany. In comparison, New Jersey and California tended to have higher levels of VOCs outdoors. Devils Lake, North Carolina had low levels of 1,1,1-trichloroethane, ethylbenzene, (*m*+*p*) xylene and *o*-xylene relative to the other cities; however it is a small rural town.

Table 5.16 Outdoor median concentrations ($\mu g/m^3$) (Cheng et al., 1997; Cohen et al., 1989; Gebefuegi et al., 1995; & Hartwell et al., 1987b).

	St. Albert		Sherwood Park		Strathcona Industrial Corridor[1]	Downtown Edmonton[2]	Germany[3]
	Fall	Winter	Fall	Winter			
1,1,1-Trichlorethane	0.6	0.3	0.6	0.3			
Carbon Tetrachloride	1.0	0.8	1.0	0.8	0.2	0.7	
Toluene	4.2		1.3		4.6	7.1	4.3
Benzene		1.6		1.2	2.6	3.4	1.6
Tetrachloroethylene	0.4	0.3	0.4	0.3	0.1	0.4	
Ethylbenzene	0.8	1.1	0.6	0.2			0.7
(*m+p*) Xylene	3.1	3.4	1.8	0.9	2.8	4.6	2.4
o-Xylene	1.0	1.2	0.6	0.5		1.9	0.8
1,3,5-Trimethylbenzene		0.3		0.1			
1,2,4-Trimethylbenzene	1.6	1.1	1.3	0.4	1.6	2.1	

	Kanawha Valley[4]	New Jersey[5]		California[6]		Greensboro[7]		Devils Lake[8]	
		Night	Day	Night	Day	Night	Day	Night	Day
1,1,1-Trichlorethane		4.7	4.1	6.6	5.9	60	76	0.05	0.07
Carbon Tetrachloride	2.3								
Toluene									
Benzene	2.5	7.9	4.5	4.2	4.8	0.4	12	---	---
Tetrachloroethylene	0.8	1.8	3.3	2.2	2.4	0.7	0.5	0.7	1.3
Ethylbenzene	1.1	2.9	2.0	3.3	3.0	0.3	0.7	0.03	0.05
(*m+p*) Xylene	2.3	9.1	6.0	11	9.7	1.5	2.9	0.05	0.07
o-Xylene	1.0	3.3	1.9	4.1	3.5	0.6	1.3	0.05	0.5
1,3,5-Trimethylbenzene									
1,2,4-Trimethylbenzene									

[1] Samples collected every 6 days for 24 hours between 1991 and 1993.

[2] Samples collected every 6 days for 24 hours between 1991 and 1993.

[3] Daytime sampling in Munich, Germany (n = 52).

[4] 3 week samples collected in Kanawha Valley, West Virginia (n = 32)

[5] Combination of summer and winter 12 hr samples in Bayonne and Elizabeth, New Jersey (n = 55 to 80).

[6] Combination of spring and winter 12 hr samples in Los Angeles and spring in Antioch and Pittsburg, California (n = 57 to 59)).

[7] 12 hr overnight samples in Greensboro, North Carolina (n= 6).

[8] 12 hr overnight samples in Devils Lake, North Dakota (n = 3 to 5).

5.5 Hypothesis Testing

The study's hypothesis states that the close proximity of Sherwood Park residences to industrial emissions of VOCs from the Strathcona industrial corridor does not significantly increase the concentrations of VOCs at the residences, indoors and outdoors. To test the study's hypothesis, the Wilcoxon Rank Sum Test (Gilbert, 1987) was used to test the difference in air concentrations (both indoor and outdoor) between Sherwood Park (community under study) and St. Albert (control community). The null hypothesis states: the average VOC concentrations in each community are the same. The rank sum test was chosen because the two data sets do not need to be drawn from normal distributions and the sample sizes from each set do not need to be equal (Gilbert, 1987). Both one and two-tailed tests were performed at the 95% confidence level, with the following alternate hypotheses:

One-tailed H_A – Sherwood Park has higher average VOC concentrations than St. Albert

Two-tailed H_A – Average VOC concentrations in each community are not equal.

Both the fall and winter data sets were used to test the study's hypothesis. Table 5.17 and Table 5.18 summarise the results of the fall and winter hypothesis testing for indoor and outdoor samples.

Table 5.17 Fall hypothesis testing results.

$\alpha = 0.05$	Indoor			Outdoor		
	Z_{rs}	One-tailed ($Z_{1-\alpha} = 1.65$)	Two-tailed ($Z_{1-\alpha/2} = 1.96$)	Z_{rs}	One-tailed ($Z_{1-\alpha} = 1.65$)	Two-tailed ($Z_{1-\alpha/2} = 1.96$)
1,1,1-Trichlorethane	0.72	Accept	Accept	-0.45	Accept	Accept
Carbon Tetrachloride	-0.27	Accept	Accept	-0.29	Accept	Accept
Toluene	0.97	Accept	Accept	-1.99	Accept	Reject
Tetrachloroethylene	-0.12	Accept	Accept	-0.88	Accept	Accept
Ethylbenzene	0.82	Accept	Accept	-1.87	Accept	Accept
(m+p) Xylene	0.87	Accept	Accept	-1.69	Accept	Accept
o-Xylene	1.00	Accept	Accept	-1.56	Accept	Accept
1,2,4-Trimethylbenzene	0.13	Accept	Accept	-1.38	Accept	Accept

Table 5.18 Results of winter hypothesis testing.

$\alpha = 0.05$	Indoor			Outdoor		
	Z_{rs}	One-tailed ($Z_{1-\alpha} = 1.65$)	Two-tailed ($Z_{1-\alpha/2} = 1.96$)	Z_{rs}	One-tailed ($Z_{1-\alpha} = 1.65$)	Two-tailed ($Z_{1-\alpha/2} = 1.96$)
1,1,1-Trichlorethane	0.30	Accept	Accept	-1.04	Accept	Accept
Carbon Tetrachloride	-0.85	Accept	Accept	-1.03	Accept	Accept
Benzene	-0.07	Accept	Accept	-0.99	Accept	Accept
Tetrachloroethylene	-1.16	Accept	Accept	-1.16	Accept	Accept
Ethylbenzene	-1.69	Accept	Accept	-3.43	Accept	Reject
(m+p) Xylene	-1.85	Accept	Accept	-2.52	Accept	Reject
o-Xylene	-1.87	Accept	Accept	-3.01	Accept	Reject
1,3,5-Trimethylbenzene	-2.16	Accept	Reject	-3.19	Accept	Reject
1,2,4-Trimethylbenzene	-1.85	Accept	Accept	-2.54	Accept	Reject

For the fall data set, the null hypothesis was accepted for all compounds, indoors and out using the one-tailed test. However, the two-tailed test revealed a statistically significant difference between toluene outdoors. The results of the hypothesis testing revealed that St. Albert had higher average concentrations of toluene outdoors than Sherwood Park. The high background contamination, reported for toluene (Table 5.2, p. 86), might have biased this result. However, the higher levels of toluene outdoors in St. Albert may be attributable to vehicle emissions. Toluene is typically a component of vehicle exhaust. As 40% of the time the wind was blowing from a southerly direction, vehicle emissions may have been transported to St. Albert from Edmonton. Several important roadways are located south of St. Albert in Edmonton. In comparison, south of Sherwood Park is primarily farmland. Although ethylbenzene and the xylenes did not have statistically significant differences, at the 95% confidence level, both the means and medians were higher in St. Albert compared to Sherwood Park outdoors. In fact, for the two-tailed test a statistically significant difference exists for ethylbenzene and (*m*+*p*) xylene at the 90% confidence level. Ethylbenzene and xylenes are also found in vehicle emissions.

Similar to the fall conclusions, the null hypothesis was accepted for all compounds, indoors and out using the one-tailed test. Therefore, it is concluded that Sherwood Park does not have higher average VOC concentrations than St. Albert, indoors or out, at the 95% confidence level. However, the two-tailed test revealed a statistically significant difference between some of the compounds, primarily outdoors: ethylbenzene, (*m*+*p*) xylene, *o*-xylene, 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene. The results of the hypothesis testing revealed that for certain compounds, St. Albert had higher average concentrations than Sherwood Park outdoors. St. Albert was also found to have higher average concentrations of 1,3,5-trimethylbenzene indoors.

The lack of a statistically significant difference between the indoor samples (except 1,3,5-trimethylbenzene) supports the conclusion that indoor air is more strongly influenced by indoor sources rather than the ambient air.

Ethylbenzene, xylene and trimethylbenzene are all found in gasoline (Cohen et al., 1989). Similar to the observation of higher levels of toluene outdoors in St. Albert, the higher levels of ethylbenzene, xylenes and trimethylbenzenes could be related to vehicle emissions. Similar to the fall, the wind blew predominately from a southerly direction, which may have transported vehicle emissions from the City of Edmonton. It is interesting that when a difference was observed, it was found that St. Albert had higher average concentrations outdoors than Sherwood Park. This supports the study's hypothesis that industrial emissions of VOCs from the Strathcona industrial corridor are not significantly increasing concentrations of VOCs inside or outside of homes in Sherwood Park.

The acceptance of this study's hypothesis is consisted with what was found by the researchers in the Kanawha Valley. Their study was also unable to find a statistically significant impact on homes located near industrial activities compared to control homes (Cohen et al., 1989).

In comparison, the TEAM studies identified a difference between outdoor air samples collected in Bayonne/Elizabeth, New Jersey and Los Angeles and Pittsburg/Antioch, California compared to Greensboro, North Carolina and Devils Lake, North Dakota. The New Jersey and California cities both have significant industrial activities where as Greensboro, North Carolina has no major industrial sources and Devils Lake is a small rural town. Outdoor air samples in Greensboro and Devils Lake were typically found to have lower levels of VOCs (Hartwell et al., 1987b). However, this finding should be regarded with caution due to the small sample sizes in Greensboro (n=6) and Devils Lake (n=5). The levels observed in Devils Lake are expected to be different from what was observed in St. Albert, as St. Albert is not a rural community. St. Albert was purposely chosen because it would experience similar urban influences to Sherwood Park. The greatest differences between the regions were found for ethylbenzene, *o*-xylene, (*m+p*) xylene and benzene. The higher levels of ethylbenzene, *o*-xylene and (*m+p*) xylene outdoors is similar to what was observed in St. Albert. However, due to the uncertainty surrounding the TEAM studies' conclusion it is difficult to make comparisons.

5.6 Indoor to Outdoor Ratios

Fall and winter indoor to outdoor (I/O) ratios were calculated for St. Albert and Sherwood Park. The results are summarised in Table 5.19. I/O ratios were greater than one for all compounds, with the exception of carbon tetrachloride. In both St. Albert and Sherwood Park the I/O ratios for carbon tetrachloride were close to one.

For the fall data set, the greatest difference between indoor and outdoor concentrations was observed in St. Albert for 1,1,1-trichloroethane with an I/O ratio of 14. However, the mean indoor concentration of 1,1,1-trichloroethane was affected by a peak concentrations (160 μg/m^3), if this value is removed the I/O ratio becomes 5.9. The next highest I/O ratio was for 1,2,4-trimethylebenzene (450 μg/m^3), also in St. Albert

(I/O = 8.3). This ratio was also affected by a peak concentration; if removed the corresponding ratio is 2.3. The highest ratio observed in the fall for Sherwood Park was for ethylbenzene (I/O = 6.1).

Table 5.19 Mean indoor to outdoor ratios for matched pairs.

	St. Albert		Sherwood Park	
	Fall (n=27)	Winter (n=30)	Fall (n=31)	Winter (n=32)
1,1,1-Trichlorethane	14	15	5.1	9.0
Carbon Tetrachloride	1.0	1.1	1.0	0.9
Toluene	1.7		4.9	
Benzene		1.6		2.2
Tetrachloroethylene	4.6	4.9	4.1	29
Ethylbenzene	7.1	2.6	6.1	4.5
(m+p) Xylene	6.8	3.8	5.2	5.7
o-Xylene	6.4	3.6	4.6	5.1
1,3,5-Trimethylbenzene		4.5		4.0
1,2,4-Trimethylbenzene	8.3	4.8	2.6	5.0

The greatest difference between winter indoor and outdoor concentrations was observed in Sherwood Park for tetrachloroethylene with an I/O ratio of 29 (Table 5.19). However, the mean indoor concentration of tetrachloroethylene was affected by a peak concentration (290 $\mu g/m^3$). If this value is removed the I/O ratio becomes 3.6. The next highest I/O ratio was for 1,1,1-trichloroethane, also in St. Albert (I/O = 15). The corresponding ratio in Sherwood Park for 1,1,1-trichloroethane was also high, I/O ratio of 9.0.

I/O ratios greater than one are consistent with findings from numerous studies. Studies done in the United States and Germany have all found indoor VOC concentrations to be higher than outdoor VOC concentrations (Pellizzari et al., 1986; Cohen et al., 1989; Gebefuegi et al., 1995). Table 5.20 summarises I/O ratios for studies done in the United States and Germany. In particular, the study done in the Kanawha

Valley of West Virginia investigated the relationship between indoor and outdoor air concentrations of VOCs for a heavily industrialised area. Despite the high concentration of industrial activities in the area, indoor concentrations were greater than outdoor concentrations (Cohen et al., 1989). This is consistent with the findings for Sherwood Park. Indoor sources of VOCs seem to have the highest potential for affecting human exposure because people spend the majority of their time indoors and indoor concentrations are generally higher than ambient concentrations.

Table 5.20 Indoor to outdoor ratios observed outside of Canada (Cohen et al., 1989; Gebefuegi et al., 1995; & Pellizzari et al., 1986).

	Germany[1]	Kanawha Valley[2]	New Jersey[3]		Los Angeles[4]	
			Fall	Winter	Summer	Winter
1,1,1-Trichlorethane			3.7	10	2.0	0.8
Carbon Tetrachloride		1.4	7.0		1.1	1.0
Toluene	2.9					
Benzene	1.0	0.8	1.9		1.7	1.1
Tetrachloroethylene		1.6	2.2	6.2	1.3	1.2
Ethylbenzene	1.4	2.5	1.9	1.1	1.1	0.9
(*m*+*p*) Xylene	1.9	3.2	1.6	1.4	1.0	0.9
o-Xylene	2.0	2.6	1.7	1.6	1.2	1.0
1,3,5-Trimethylbenzene						
1,2,4-Trimethylbenzene						

[1] Calculated from reported mean indoor and outdoor concentrations for Munich, Germany

[2] Calculated from reported median indoor and outdoor concentrations (n = 35).

[3] Reported overnight indoor to outdoor ratios for Elizabeth-Bayonne, N.J. (Fall, n = 85; Winter n = 9)

[4] Reported overnight indoor to outdoor ratios for Los Angeles, Ca. (Summer, n = 23; Winter n = 23).

Chapter 6: Conclusions & Recommendations

The results of this study support a hypothesis that: the close proximity of Sherwood Park residences to industrial emissions of volatile organic compounds from the Strathcona industrial corridor does not significantly increase the concentrations of VOCs at receptor locations inside and outside of homes. Average indoor and outdoor concentrations of several VOCs at receptor locations in Sherwood Park were not found to be statistically greater than the average concentrations at receptor locations in St. Albert. In fact, St. Albert was found to have statistically significant higher outdoor concentrations of certain VOCs compared to Sherwood Park: toluene, ethylbenzene, (*m*+*p*) xylene, *o*-xylene, 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene. Due to the uncertainties associated with the outdoor winter samples additional research would be required to verify the observed difference between St. Albert and Sherwood Park. Moreover, additional research would be required to accurately correlate outdoor measurements with wind direction frequencies and ambient sources.

Despite the differences in outdoor concentrations, it is significant that most of the compounds were found to have similar indoor mean concentrations in both communities. This suggest that indoor sources are the predominant factor determining indoor concentrations rather than ambient influences. If industrial emissions are not having a significant affect on indoor air quality the potential for associated health effects decreases because indoors is the receptor location where humans face their greatest potential for exposure.

In addition to addressing the study's hypothesis the data collected were used to examine indoor concentrations in Sherwood Park and St. Albert compared to other regions. The results of this study were consistent with other studies. Indoor concentrations were found to be similar to levels seen in the United States, Germany and elsewhere in Canada. From this it can be concluded that indoor sources and activities common to industrialised nations are the predominant influencing factors on indoor concentrations. Outdoor concentrations tended to be of the same magnitude or lower than what was found in other studies.

An additional objective identified at the beginning of the study was to examine if humans are being exposed to higher levels of VOCs outdoors or within their own homes. To facilitate this, indoor to outdoor ratios were calculated for both communities. With the exception of carbon tetrachloride, the ratios for all the compounds examined were greater than one. This leads to the conclusion that humans are exposed to higher levels of VOCs within their own homes. As humans spend the majority of their time indoors and the highest concentrations of VOCs are typically found indoors, their greatest potential for exposure will occur indoors. The health risks posed to humans by exposure to industrial emissions seem to be small in comparison to exposures related to the home microenvironment.

A final conclusion drawn from this study is that the primary determinants of indoor concentrations of VOCs are indoor sources and/or activities. The high variability observed between the indoor concentrations suggests that they are dependent on localised sources. Individual characteristics of the house and the activities within it have the greatest impact on concentration compared to ambient sources. Indoor to outdoor ratios support this conclusion. I/O ratios greater than one suggest a build up or maintenance of pollutants within the home that are resulting from indoor sources. In comparison, outdoor concentrations tended to be less variable suggesting that outdoor samples were influenced by similar conditions within and surrounding the communities.

Execution of this study yielded considerations that should be addressed if a similar study was performed. The main recommendation would be to increase sampling time from 24 hours to 4 to 7 days. The short sampling time resulted in lower quantities of compounds being collected. If the sampling time was increased, larger amounts of compounds could be collected which would improve the analytical confidence. Secondly it would be beneficial to clean all the carbon disulphide required for the study as a batch. This would require a clean storage environment as carbon disulphide is easily contaminated. Cleaning the carbon disulphide in a batch would reduce bias induced by differences in CS_2 contamination from batch to batch. Moreover, using an internal standard for the GC/MS analysis as opposed to an external standard would increase analytical confidence. Lastly, all outdoor monitors should be protected from the elements, particularly if sampling time is increased. However, the shelters should be designed to allow sufficient airflow.

Chapter 7: References

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8.1 *Recruitment Brochure*

Community Air Sampling Program

UNIVERSITY OF ALBERTA

Capital Health

Two researchers from the University of Alberta will be in your area during the month of September. The researchers will be recruiting volunteers for an air quality study. About 35 volunteers are needed from your area. The objective of the study is to test if that being close to industry increases the levels of air pollutants in homes.

This study is a result of concerns raised by residents of Sherwood Park regarding the quality of the air in their community. Air pollutants will be monitored at the homes of volunteers in Sherwood Park and St. Albert.

Air sampling at your home will be done in the fall and winter over 24 hours. The monitors are small and noiseless. Volunteers will be needed for a few hours over two days in both the fall and winter. The time requirement considers drop-off and pick-up of samplers, plus the completion of a questionnaire.

Your participation is vital to the success of this research. With your help, valuable information on the quality of the air in Sherwood Park and St. Albert can be gained.

Principal Investigator:
Dr. Warren Kindzierski
University of Alberta

Co-Investigators:
Dr. Ken Froese (U of A)
And
Dr. Daniel Smith (U of A)

August 1998

For more information please contact:

Christine Byrne
University of Alberta

or

Steven Probert
Capital Health Authority

at 492-8548

8.2 *Second Attempt Notice*

Capital
Health

UNIVERSITY OF ALBERTA

Sorry We Missed You!

In early September, a notice was left at your house regarding an air quality study being done in Sherwood Park and St. Albert. This evening we were in your neighborhood to recruit volunteers for the study. Volunteering involves allowing us to place a small, silent air sampler in your home for a period of 24 hours, and the completion of a 10-minute questionnaire.

Your participation in this study would be greatly appreciated. If you are interested or would like to volunteer, please call Steve or Christine at 492-8548.

Thank you,

Steven Probert
Capital Health

Christine Byrne-Lewis
University of Alberta

8.3 *Recruitment Package*

Capital
Health
Environmental Health

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

September 1998

Dear Resident:

I am writing to tell you about a joint study we are doing with two graduate students from the University of Alberta. We want to measure concentrations of air pollutants inside and outside of homes in Sherwood Park and St. Albert. This data will be used to examine if industrial emissions affect the quality of the air in your community.

Attached is an information sheet that will answer some of the questions you may have about the study. Participation in the study is up to you. We would be pleased if you would participate. If you choose not to participate, services provided to you by the Capital Health Authority will not be affected.

Thank you very much.

Sincerely,

Dr. Gerry Predy
Medical Officer of Health
Capital Health Authority

Dr. Warren Kindzierski
Department of Civil and Environmental Engineering
University of Alberta

Capital Health
Environmental Health

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

Title of Project:	***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***	
Principal Investigator:	Dr. Warren Kindzierski University of Alberta 492-0247	
Co-Investigators:	Dr. Ken Froese University of Alberta	Dr. Daniel Smith University of Alberta
Field Investigators:	Steven Probert Capital Health Authority 492-8548 or 413-7927	Christine Byrne-Lewis University of Alberta 492-8548

Purpose of Research:

Public concern exists about the effect of local industries upon air quality and health. Capital Health is working with the University of Alberta to look into this issue more closely.

Background Information:

The environment in which we live is important to our health. We receive exposure to pollution in our air, food, water, and soil. This study focuses on industrial pollution and its effect on local air quality.

The air pollutants being investigated are volatile organic compounds (VOC). Some common sources include cars, industries, forest fires, cigarette smoking, building materials, and cleaning products.

Why did you approach me to participate?

There was a random selection of homes from within the community.

What if I do not want to participate?

You do not have to participate in this study. If you do not participate, it will not affect any of the services provided to you.

Capital Health
Environmental Health

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

What is my role as a participant?

Your participation involves the completion of a questionnaire and allowing us to place air samplers at your home in the fall and winter seasons. At our first visit, in September 1998, we explain the study and answer your questions. If you consent to participate, you will receive a short (~10min) questionnaire to complete about the characteristics of your home.

At the second scheduled visit, we place some small, silent air samplers inside and outside of your home.

At the third scheduled visit, 24 hours later, we pick-up the samplers and questionnaire. We also briefly (~15 min) interview you about possible indoor VOC sources.

Your participation during January or February repeats the above procedure.

Are there any risks or benefits?

There are no health and safety risks associated with this study.

The direct benefits include the results of your home's air quality. The field investigators will report the results of the study in their graduate theses. This information will be available upon request in August 1999.

How will the information collected be kept confidential?

The records relating to this study are confidential. The investigators and Capital Health will have access to these records to develop research reports. Any report published as a result of this study will not identify you by name.

Whom can I call with questions?

If you have questions about this study you may contact Steven or Christine. If you have concerns about the nature of this study, you may also call the Patient Concerns Office of Capital Health (492-4845). This office has no direct affiliation with the investigators.

8.4 Consent Form

Capital Health

Environmental Health

UNIVERSITY OF ALBERTA

Civil and Environmental Engineering

Research Id #: ____________________

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators:	Dr. Ken Froese University of Alberta	Dr. Daniel Smith University of Alberta
Field Investigators:	Steven Probert Capital Health Authority 492-8548 or 413-7927	Christine Byrne-Lewis University of Alberta 492-8548

Please complete this short form:

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the Information Sheet?	Yes	No
Do you understand the benefits and that there are no risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason.	Yes	No
Has the issue of confidentiality been explained to you?	Yes	No

This study was explained to me by:
Steven Probert ☐
Christine Byrne-Lewis ☐

Capital
Health

Environmental Health

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

I agree to take part in this study:

Signature of Participant ____________________ Date ____________________

Printed Name ____________________ Phone No. ____________________

Street Address ____________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate:

Signature of Investigator ____________________ Date ____________________

A COPY OF THE INFORMATION SHEET MUST BE GIVEN TO THE PARTICIPANT.

8.5 Questionnaires

Capital
Health

Environmental Health

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

QUESTIONNAIRE: HOUSEHOLD CHARACTERISTICS

Research Id #: ____________________ Date received: ____________________

Title of Project:	***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***	
Principal Investigator:	Dr. Warren Kindzierski University of Alberta 492-0247	
Co-Investigators:	Dr. Ken Froese University of Alberta	Dr. Daniel Smith University of Alberta
Field Investigators:	Steven Probert Capital Health Authority 492-8548 or 413-7927	Christine Byrne-Lewis University of Alberta 492-8548

Instructions:

This questionnaire is for you to complete before our next appointment. Please answer the questions by printing in the spaces provided, or by placing a check-mark in the correct box.

Your answers help to determine things about your home that may affect indoor air quality. Before you mark a question as "unknown", please refer to the glossary of terms for unfamiliar words or contact Christine or Steven for help. You can contact them by telephone or wait for them to return for their next appointment.

Thank-you for your co-operation.

A. Household and Participant Identification:

1. Participant Name: ____________________________________

2. Participant Phone No.: ____________________________________

3. Street Address: ____________________________________

4. City/Hamlet: ____________________________________

B. Household Habitants:

5. Who are the regular habitants of the house?

Person #	**1**	**2**	**3**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			
Person #	**4**	**5**	**6**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			

Age Categories: 1 is <1 year old
2 is 1to 5 years old
3 is 6 to 11 years old
4 is 12 to 19 years old
5 is over 20 years old

C. Type of House:

6. What type of a house do you live in?

☐ single family house ☐ duplex/triplex/quadruplex
☐ row/townhouse other______________________________

7. Which one of the following best describes your house?

☐ bungalow ☐ bilevel ☐ two story
☐ split level other ______________________________

8. How big is the house, excluding the basement? Please circle the units used. ______________________square feet or square metres

9. Do you have a finished basement?

☐ yes ☐ no ☐ unknown

10. How big is the basement? Please circle the units used.

______________________square feet or square metres

11. In what year was the house originally built? ___________________

12. Do you have an indoor swimming pool or indoor whirlpool?

☐ yes ☐ no ☐ unknown

D. Heating, Ventilation, and Air Conditioning Systems:

13. Does the house have an air conditioner?

☐ yes ☐ no ☐ unknown

If yes, what type? ☐ central ☐ room

If it's a room air conditioner, what room is it in?________________

14. Does the house have any fans for extra ventilation?

☐ yes ☐ no ☐ unknown

If yes, what type(s)? ☐ portable fan ☐ ceiling fan

Location(s)? ____________________

15. Does the house have an air purification system installed?

☐ yes ☐ no ☐ unknown

If yes, what type? ____________________

16. Does the house have any exhaust system (eg. range hood, fumehood)?

☐ yes ☐ no ☐ unknown

If yes, where is it? ____________________

Where does it vent to? ☐ outside ☐ inside

17. How do you heat your home? Indicate the type of heating systems in the below table, by marking the appropriate box with either 1^0 (main) or 2^0 (secondary) heating system. Also indicate the location of fireplaces, recreational stoves, and room heaters.

	Type of Fuel				**Location**
Type of System	n gas	elec	wood	other	
forced air furnace					
gravity furnace					
radiant heat - wall					
radiant heat - floor					
fireplace/stove					
room heater					
portable heater					
other ________					
other ________					

18. Do you maintain the thermostat at a constant temperature throughout the day? ☐ yes ☐ no ☐ unknown

19. Does the heating system have a combustion air supply?

☐ yes ☐ no ☐ unknown

20. Does the heating system have a fresh air return?

☐ yes ☐ no ☐ unknown

E. Attached Structures:

21. Does the house have any attached structures?

☐ yes ☐ no ☐ unknown

If yes, what type(s)? ☐ garage ☐ shed/shop
☐ greenhouse ☐ other

If no then go to *Comments* on page 6.

22. Does the attached structure(s) have a door that opens into the house?

☐ yes ☐ no ☐ unknown

If yes, is this door(s) usually kept closed?

☐ yes ☐ no ☐ unknown

23. Does the attached structure have a heating system?

☐ yes ☐ no ☐ unknown

If yes, what type? Please use the categories listed in question (17).

____

24. Does the attached structure have any ventilation or exhaust system(s)?

☐ yes ☐ no ☐ unknown

If yes, what type?

☐ window/overhead door ☐ exhaust system ☐ fan

If exhaust, where does it vent to? ☐ outside ☐ inside

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GLOSSARY OF TERMS:

If the term you are looking for is not here or you still do not understand the question then please contact one of the investigators.

attached structure	a building which is physically connected to your home. This may include a garage, shed, greenhouse, etc.
combustion air supply	an (insulated) air duct/pipe which provides an air supply from outside to the furnace room. It is not directly attached to the furnace and it usually ends just above the floor with a perforated cap.
duct	a pipe which moves air through the house.
exhaust system	an electric fan which draws air out of an area and blows it outside (vents outside), or an electric fan which circulates the air through a filter and blows it back inside (vents inside).
fireplace/stove	a wood, gas, or coal fueled fire burning unit.
forced air furnace	a furnace that pushes warm air through the furnace ducts with an electric fan.
fresh air return	an (insulated) air duct which supplies fresh air from outside to the furnace. It is directly attached to the furnace's air intake duct.
gravity furnace	an older style furnace where the warm air rises naturally through the furnace's air ducts without the aid of a fan.

mechanical	a motorized system requiring power to run.
portable heater	a heater which is fueled by propane, kerosene, or electricity and can be easily moved from room to room.
radiant heat	a heating system which circulates hot water from a boiler through pipes located throughout the house. The heat from the hot water is given off (radiated) these pipes which either run along the base of the walls, or run underneath the floor.
room heater	a fixed heater located in a specific room which is intended to supplement the main heating system.
single family house	a structure which was originally designed to accommodate a single family.
vent	process of blowing air or fumes out the end of a pipe. If the air is blown to the outside then this is venting outside, if the air is blown back inside of the house then this is venting inside.
ventilation	the movement of air in a space. It can be either mechanical ventilation through the use of an electric fan, or it can be natural ventilation achieved by opening windows or doors.

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QUESTIONNAIRE: HOUSEHOLD ACTIVITIES

Research Id #: ______________

Interviewer: ______________

Date: ______________

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators:

Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators:

Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

F. Household Sources of VOCs:

25. Are all of your household appliances (cooking stove, hot water heater, clothes dryer, etc.) electric? If no, please complete the below table.

☐ yes ☐ no ☐ unknown

	Type of Fuel ( )		
Type of Appliance	natural gas	other (specify)	location
cooking stove			
hot water heater			
clothes dryer			
other ________			

26. Do you ever use the cooking stove for heating your home?

☐ yes ☐ no ☐ unknown

27. Is the clothes dryer vented to the outside?

☐ yes ☐ no ☐ unknown

28. Is your home carpeted?

☐ yes ☐ no ☐ unknown

If no, then go to 31.

29. How much carpet would you guess your home has?

☐ <25% ☐ 25 to 50% ☐ 50 to 75% ☐ >75%

30. Has any part of the house had carpet installed within the past year?

☐ yes ☐ no ☐ unknown

If yes, than within past: ☐ 3 months ☐ 6 months

G. Household Activities:

31. Did anyone have the drapes, carpeting, or furniture professionally cleaned this past week?

☐ yes ☐ no ☐ unknown

32. Did anyone pick-up any clothing from the dry-cleaners this past week?

☐ yes ☐ no ☐ unknown

33. Did anyone leave any windows open over the past 24 hours?

☐ yes ☐ no ☐ unknown

34. Do people smoke inside the house or any of the attached structures?

☐ yes ☐ no ☐ unknown

35. Do you have any of the following items? Where is it stored? Did you use it recently, and if so where? Please complete the below table.

Item	Do you have? (y/n)	Storage location? Specify floor and room.	Recent use? (n/d/wk)	Where was recent use? Specify floor and room if different from storage location.
Gas, oil				
Propane				
Other fuels				
Vehicles				
Rec. vehicles				
Pesticides/ Fertilizers				
Paint or varnish				
Solvents				
Glues				
Dirty work clothing				
Clean/disinf. agents				
Air deodorants				
Mothballs				
Cosmetic or hair products				
Aerosol spray				
Office equip.				

36. Did anyone perform one of the following activities within the house or attached structure in the past week?

- scale model building: ☐ yes ☐ no ☐ unknown
- artwork: ☐ yes ☐ no ☐ unknown
- furniture refinishing: ☐ yes ☐ no ☐ unknown
- metal working: ☐ yes ☐ no ☐ unknown
- welding: ☐ yes ☐ no ☐ unknown
- plastics work: ☐ yes ☐ no ☐ unknown
- auto body work: ☐ yes ☐ no ☐ unknown
- mechanical repairs: ☐ yes ☐ no ☐ unknown
- degreasing (oven/BBQ): ☐ yes ☐ no ☐ unknown
- **renovations/redecorating:**
- painting/varnishing: ☐ yes ☐ no ☐ unknown
- gluing/caulking: ☐ yes ☐ no ☐ unknown
- re-flooring: ☐ yes ☐ no ☐ unknown
- tiling: ☐ yes ☐ no ☐ unknown
- plumbing: ☐ yes ☐ no ☐ unknown
- new furniture: ☐ yes ☐ no ☐ unknown

other:____

____

____

____

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WINTER QUESTIONNAIRE: CHANGES TO HOUSEHOLD CHARACTERISTICS AND HOUSEHOLD ACTIVITIES

Research Id #: ____________________ Date received: ____________________

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator:	Dr. Warren Kindzierski University of Alberta 492-0247	
Co-Investigators:	Dr. Ken Froese University of Alberta	Dr. Daniel Smith University of Alberta
Field Investigators:	Steven Probert Capital Health Authority 492-8548 or 413-7927	Christine Byrne-Lewis University of Alberta 492-8548

Instructions:

This questionnaire is to be completed through an interview by one of the field investigators. Please answer the questions by printing in the spaces provided, or by placing a check-mark in the correct box. The answers help to determine things about your home that may affect indoor air quality.

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A. Changes to Household Characteristics:

1. Have any major renovations been performed on the house since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify. ______________________________

____

____

____

2. Have any changes been made to the heating, ventilation or air conditioning systems since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify. ______________________________

____

____

____

3. Have any major appliances been added, removed or changed in the house? ☐ yes ☐ no ☐ unknown

If yes, please specify. ______________________________

____

____

____

4. Have any major renovations been made to the attached structures or an attached structure been added since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify. ______________________________

____

____

____

5. Are the regular habitants of the house the same, or have any of them changed status? Please note changes in the below table.

Person #	**1**	**2**	**3**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			

Age Categories: 1 is <1 year old
2 is 1to 5 years old
3 is 6 to 11 years old
4 is 12 to 19 years old
5 is over 20 years old

Comments:

____

____

____

____

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____

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____

____

____

____

B. Household Activities:

6. Did anyone have the drapes, carpeting, or furniture professionally cleaned this past week?

☐ yes ☐ no ☐ unknown

7. Did anyone pick-up any clothing from the dry-cleaners this past week?

☐ yes ☐ no ☐ unknown

8. Did anyone leave any windows open over the past 24 hours?

☐ yes ☐ no ☐ unknown

9. Do people smoke inside the house or any of the attached structures?

☐ yes ☐ no ☐ unknown

10. Do you have any of the following items? Where is it stored? Did you use it recently, and if so where? Please complete the below table.

Item	Do you have? (y/n)	Storage location? Specify floor and room.	Recent use? (n/d/wk)	Where was recent use? Specify floor and room if different from storage location.
Gas, oil				
Propane				
Other fuels				
Vehicles				
Rec. vehicles				
Pesticides/ Fertilizers				
Paint or varnish				
Solvents				
Glues				
Dirty work clothing				
Clean/disinf. agents				
Air deodorants				
Mothballs				
Cosmetic or hair products				
Aerosol spray				
Office equip.				

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1. Did anyone perform one of the following activities within the house or attached structure in the past week?

- scale model building: ☐ yes ☐ no ☐ unknown
- artwork: ☐ yes ☐ no ☐ unknown
- furniture refinishing: ☐ yes ☐ no ☐ unknown
- metal working: ☐ yes ☐ no ☐ unknown
- welding: ☐ yes ☐ no ☐ unknown
- plastics work: ☐ yes ☐ no ☐ unknown
- auto body work: ☐ yes ☐ no ☐ unknown
- mechanical repairs: ☐ yes ☐ no ☐ unknown
- degreasing (oven/BBQ): ☐ yes ☐ no ☐ unknown
- **renovations/redecorating:**
  - painting/varnishing: ☐ yes ☐ no ☐ unknown
  - gluing/caulking: ☐ yes ☐ no ☐ unknown
  - re-flooring: ☐ yes ☐ no ☐ unknown
  - tiling: ☐ yes ☐ no ☐ unknown
  - plumbing: ☐ yes ☐ no ☐ unknown
  - new furniture: ☐ yes ☐ no ☐ unknown
  - other:____

____

____

____

8.6 VOC List with Screening Process

Legend

AEP - Alberta Environmental Protection
CAA - Clean Air Act
CEPA PSL1 - Canadian Environmental Protection Act Priority Substance List 1
CIAQS - Canadian Indoor Air Quality Study
GC/MS - Gas Chromatography - Mass Spectrometry
TEAM - Total Exposure Assessment Methodology studies

Volatile Organic Compounds	*Reasons for Choice*	*Potential Health Effects*	*Ind. Air Emission*	*Common Indoors (10)*	*Odour (Air odor threshold ppm;v/v)a*	*OVM 3500*	*GC/MS*
1,1,1 Trichloroethane	TEAM-ubiquitous (1)	CEPA PSL1 (4)		*Yes (1,6)*		*YES*	*YES*
1,1,2 Trichloroethane		AEP (7); CAA (3)				*YES*	*YES*
1,1,2,2-Tetrachloroethane	CIAQS (2)	AEP (7); CAA (3)		*No (1,2)*	1.5	*YES*	*YES*
1,1-Dichloroethane						*YES*	*YES*
1,2,3-Trichloropropane						*YES*	*YES*
1,2,4-Trimethylbenzene (mesitylene)	Released by industry (10); CIAQS (2)		*Yes*	*Yes*		*YES*	*YES*
1,3,5-Trimethylbenzene						*YES*	*YES*
Acetone	Released by industry (10)		*Yes*	*Yes (6)*	13	*YES*	*YES*
Benzene	AEP (2.48 ug/m3) (7); Released by industry (10); TEAM-ubiquitous (1); CIAQS (2)	AEP (7); CEPA PSL1 (4); CAA (3)	*Yes*	*Yes (1,2)*	12	*YES*	*YES*
Bromoform		known or suspected to cause carcinogenicity (9)				*YES*	*YES*
Carbon Tetrachloride	AEP (0.75 ug/m3) (7); TEAM-often present (1)	AEP (7); CEPA PSL1 (4); CAA (3)		*Yes (1)*	96	*YES*	*YES*
Chlorobenzene		believed to cause chronic systemic toxicity due to long term exposure (9)		*Yes (5)*		*YES*	*YES*
Chloroform (trichloromethane)	AEP (0.10ug/m3) (7); TEAM-often present (1); CIAQS (2)	AEP (7); CAA (3)		*Yes (1,2,6)*	85	*YES*	*YES*
Cumene (isopropylbenzene)	Released by industry (< 1 metric tonne) (10)	CAA (3)	*Yes*		0.088	*YES*	*YES*
Ethylbenzene (benzene tetrahydride, 1,2,3,4-tetrahydrobenzene)	Released by industry (10); TEAM-ubiquitous (1); CIAQS (2)	CAA (3)	*Yes*	*Yes (1,2,5,6)*	2.3	*YES*	*YES*
Ethylene Dichloride (1,2 Dichloroethane)	CIAQS (2)	AEP (7); CEPA PSL1 (4)		*No (1,2)*	88	*YES*	*YES*
Hexachlorobutadiene		known or suspected to cause carcinogenicity (9)				*YES*	*YES*
1,3-Dichlorobenzene, 1,4-Dichlorobenzene	TEAM-often present (1); CIAQS-1,3-non-detect (2)	1,4 - CAA (3)		*Yes (1,2)*		*YES*	*YES*
Methyl isobutyl ketone (Hexone, 4-Methyl-2-pentanone)	Released by industry (10)	CAA (3)	*Yes*		0.68	*YES*	*YES*

Volatile Organic Compounds	*Reasons for Choice*	*Health Effects*	*Ind. Air Emission*	*Common Indoors*	*Odour (Air odor threshold ppm;v/v)*[8]	*OVM 3500*	*GC/MS*
Naphthalene	Released by industry (10); CIAQS (2)	CAA (3)	*Yes*	*Yes(2)*	0.084	*YES*	*YES*
Styrene	Released by industry (10); TEAM-ubiquitous (1); CIAQS (2)	CAA (3)	*Yes*	*Yes (1,2,6)*	0.32	*YES*	*YES*
Tert-butyl alcohol (2-methyl-2-propanol, trimethyl carbinol, isobutanol)	Released by industry (10)		*Yes*			*YES*	*YES*
Tetrachloroethylene (Perchloroethylene, Tetrachloroethene)	Released by industry (< 1 metric tonne) (10); AEP (0.13 ug/m3) (7); TEAM-ubiquitous (1); CIAQS (2)	AEP(7); CEPA PSL1 (4); CAA (3)	*Yes*	*Yes (1,2,5,6)*		*YES*	*YES*
Toluene	Released by industry (10), 9 of top 10 measured by AEP ($4.43 \mu g/m^3$) (7); CIAQS (2)	CAA (3)	*Yes*	*Yes (2,5,6)*	2.9	*YES*	*YES*
Trichloroethylene (Trichloroethene, ethylene trichloride, triclene)	TEAM-often present (1); CIAQS (2)	CEPA PSL1 (4); CAA (3)		*Yes (1,2)*	28	*YES*	*YES*
Xylene (*m*-, *o*-, *p*-)	Released by industry (10); TEAM-ubiquitous (1); CIAQS (2)	CAA (3)	*Yes*	*Yes (1,2,5,6)*	1.1	*YES*	*YES*

1. TEAM studies found to be one of the eleven most prevalent indoor, toxic VOCs (Wallace, 1986).
2. Canadian residential IAQ study (CIAQS) found this air toxic (Fellin and Otson, 1993).
3. Hazardous air pollutants listed under U.S Clean Air Act (1990) (EPA, 1999).
4. Canadian Environmental Protection Act, Priority Substance List 1 (Health Canada, 1999).
5. Common indoor air pollutants (Brooks and Davis, 1992, p.36).
6. Common indoor air pollutants (Otson and Fellin, 1992, pp370-371).
7. Reported concentrations and/or AEP describes as hazardous pollutant in (Bates, 1996).
8. Air odor thresholds (Amoore and Hautala, 1983, Table 2(a)).
9. Known and suspected toxic substances (OECD, 1995, p 237-238).
10. 1995 National Pollutant Release Inventory (NPRI) (Environment Canada, 1999).

Industrial Pollutant (refer to Appendix 8.7 for list of potential industrial sources)

8.7 Industries Reporting to NPRI Used for Pollutant Identification

AT Plastics Inc.

Clover Bar Thermal Generating Station

Ostrem Chemical Co. Ltd.

AltaSteel Ltd.

Celanese Canada Inc. – Edmonton Facility

Owens-Corning Edmonton Plant

Triple M Fiberglass MFG Ltd.

Reliable Engine Services Ltd.

Praxair Products Inc.

Daam Galvanizing Inc.

Usine D'Acetylene/Edmonton

Strathcona Refinery – Imperial Oil

Edmonton Refinery- Petro-Canada

Alberta Envirofuels Inc.

Shaw Pipe Protection 2

Diversey Lever Canada – Edmonton

Raylo Chemicals Inc.

Titan Foundry Ltd.

8.8 VOC Instrumentation Method

VOC Instrumental Method
(Jeff Rose, Public Health Sciences, University of Alberta, Edmonton)

1. To insure that the sample loss was not significant, time trial samples were run over several weeks to determine shelf life.
2. Because the volume of CS2 was not properly measured for each sample, the internal standard, which was added after the badges were rinsed, became redundant. Therefore an external calibration curve was produced.
1. LOL (limits of linearity) was not properly determined but all of the sample amounts fell within the linear range.
2. Sensitivity was determined for each compound during each run to account for fluctuations in noise. MDL's were determined by measuring 3 times the noise level. The reported method detection limits were then determined by taking the mean of 7 random samples.
3. The LOQ (limit of quantitation) was determined by taking 10 times the standard deviation of (7 runs) of a low-level mixture (50 ppb for all compounds).
4. Response factors were determined for each compound by plotting a linear six-point calibration curve.
5. Independent check samples were analyzed every batch (every ten samples) to ensure stability of the response.
6. Instrumental and solvent blanks were also run each batch.
7. Individual compounds were positively identified based on their mass spectra. Several compounds had similar spectra and were identified by their retention times.
8. You have the instrumental parameters (ie, oven temperature programs)
9. 2.0μL of sample was injected on each run.
12. A summary of the Saturn 2000 optimised parameters for each compound is supplied on the following page:

EPA 524 Mix A

						Parent		Mass
Segment	Mass			Component	Retention	Molecular	Quant	Defect of
Number	Defect	D	#	Name	Time	Mass	Ion(s)	Quan Ion
(2) 5.48-6.90	0	T	4	1,1-Dichloroethane	6.478	98	63	32
(3) 6.90-7.82	-66	T	7	Chloroform	7.018	118	83, 85	-53
		T	9	1,1,1-Trichlorethane	7.297	132	97, 99	-19
		T	11	Carbon Tetrachloride	7.585	152	117, 119	-71
(4) 7.82-8.62	0	T	12	1,2-Dichloroethane	8.051	98	62, 64	20
		T	13	Benzene	8.017	78	51 (from 78)	137
(5) 8.62-11.00	-66	T	14	Trichloroethylene	9.300	130	130, 132	-50
(6) 11.00-12.80	68	T	19	Toluene	12.217	92	91, 92	137
(7)12.80-14.25	-40	T	21	1,1,2-Trichloroethane	13.355	132	97, 83	-19
		T	22	Tetrachloroethylene	13.582	164	166, 164, 131, 129	-64
(8) 14.25-17.25	0	T	26	Chlorobenzene	16.042	112	112, 114	61
		T	27	Ethylbenzene	16.370	106	91	137
		T	29,30	(*m+p*) xylene	16.725	106	91, 106	137
(9) 17.25-18.29	60	T	31	*o* xylene	17.931	106	91, 106	137
		T	32	Styrene	18.006	104	104	137
(10) 18.29-18.85	-91	N	33	Bromoform	18.609	250	173	-85
(11) 18.85-19.61	78	N	34	Isopropylbenzene	19.109	120	105, 120	143
(12) 19.61-20.53		N	35	1,1,2,2-Tetrachloroethane	20.285	166	83, 85	-53
		N	36	1,2,3-Trichloropropane	20.285	146	75, 110	40
(13) 20.53-22.66	67	N	40	1,3,5-Trimethylbenzene	21.051	120	105, 120	
		N	43	1,2,4-Trimethylbenzene	22.278	120	105, 120	
(14) 22.66-23.88	-21	N	46	1,3-Dichlorobenzene	23.163	146	146, 148	
		N	47	1,4-Dichlorobenzene	23.484	146	146, 148	
(15) 23.88-35.00	0	N	52	Hexachlorobutadiene	30.986	258	225, 227	
		N	53	Naphthalene	31.157	128	128	
(6) 11.00-12.80	68	X	IS	Toluene-d8	12.030	100	98	137
(15) 23.88-35.00	0	X	IS	Naphthalene-d8	31.063	136	136	

8.9 *Calculation of Air Concentrations*

The calculation procedure is based on the equation recommended in 3M (1998).

$$C(\mu g / m^3) = \frac{W(ng) \times A}{r \times t(\min)} \times CF_T$$

Where:

C = Time-weighted average concentration ($\mu g/m^3$)
W = Contaminant weight corrected for blank (ng)
A = Calculation Constant
r = Recovery Coefficient
t = Exposure time (min)
CF_T = Temperature Correction Factor

Assumptions

- BDL values substituted with ½ MDL
- Background contamination determined from trip blanks subtracted from weight
    - If > BDL – calculate time-weighted average concentration
    - If < BDL – substitute ½ MDL
- Recovery coefficient and calculation constants from 3M (1998)
- Exposure time as recorded in log book
- $CF_T = -0.0017T + 1.04$
    - Based on table in 3M (1998)
    - Indoor temperature is the average of readings taken during deployment and retrieval of monitors
    - Outdoor temperature is a two-day average temperature calculated from Environment Canada data

8.10 Fall Results

Time Weighted Average Concentrations (µg/m^3)

#	PSD	1,1,1-Trichloro ethane	Carbon Tetra chloride	Toluene	Tetrachlor oethylene	Ethyl benzene	(*m+p*) xylene	*o*-xylene	1,2,4-Trimethyl benzene
[redacted]									
27	JA9723	13	1.1	20	13	4.8	16	3.5	3.7
136	TK5882	2.8	1.2	25	1.3	4.6	17	6.2	5.5
5	TC0053	2.8	0.99	35	1.2	3.1	10	3.0	6.0
129	TK5999	160	0.18	30	46	4.3	13	5.7	5.7
48	JA9694	1.5	1.5	6.1	0.64	1.5	5.3	1.5	3.1
134	TK5873	0.56	1.0	23	2.2	5.6	19	8.6	41
29	JA9641	0.76	1.1	3.2	0.33	0.88	2.8	1.0	1.7
85	KU9264	6.2	0.85	55	2.7	11	36	11	11
125	JD2610	1.3	1.1	44	6.5	190	630	220	450
3	TC0047	1.8	0.18	14	1.1	2.4	7.4	2.1	3.5
44	JA9773	1.1	0.83	3.5	0.25	1.2	4.3	1.5	2.4
145	KU6537	20	2.7	9.0	0.55	2.2	6.6	2.0	2.3
52	JC7901	35	0.78	12	0.61	1.9	6.0	2.2	3.1
103	JP2620	3.2	0.70	5.2	0.92	1.4	4.9	1.9	2.0
76	JC7805	1.9	0.88	9.3	0.62	0.60	2.5	0.98	1.9
13	TC0046	1.9	1.1	30	4.9	3.9	16	5.3	6.7
17	KT9991	1.1	1.0	37	11	3.1	10	3.8	6.0
72	JC7937	0.66	0.95	7.7	0.62	5.0	19	7.5	15
87	JD2591	15	1.6	39	2.7	12	49	14.5	12
46	JA9867	0.36	0.73	4.5	0.25	1.2	3.5	0.66	1.8
101	JP2177	0.80	0.92	14	5.2	1.8	5.7	2.0	4.9
99	JD2604	1.0	1.1	2.4	1.1	1.4	3.7	1.3	1.8
112	JD2562	0.63	0.92	7.5	0.22	0.64	2.3	0.43	3.5
123	JP1850	2.1	0.55	9.6	0.80	0.60	2.8	1.3	2.6
25	JA9679	0.32	0.72	2.0	0.25	0.96	3.3	1.3	2.9
54	JA9787	0.49	0.72	3.4	0.25	3.4	14	4.9	6.4
114	JD2432	0.53	0.92	5.8	2.4	2.7	10	3.0	3.0
15	KT9957	1.3	0.97	9.7	1.4	2.5	8	3.6	5.6
81	JD2581	0.70	1.3	13	0.25	2.9	10	3.5	3.7
[redacted]									
19	JA9809	4.1	0.81	32	1.2	6.1	25	7.9	6.8
108	TK5855	1.4	0.92	16	0.04	34	12	3.0	6.4
118	JP2280	15	0.66	2.2	0.37	2.2	6.9	1.9	2.6
9	KT9962	8.8	0.90	60	6.0	12	46	16	22
11	TC0080	9.7	0.18	25	1.4	2.6	9.1	3.6	5.2
62	JP2231	0.42	0.66	0.10	0.25	0.10	0.12	0.15	0.84
97	JD2500	7.0	0.51	41	4.4	4.8	17	5.9	4.7
131	JP1875	2.2	1.5	22	2.6	2.4	9.2	3.1	2.3
31	JA9728	0.61	1.3	12	0.81	1.7	7.4	2.7	2.5
33	JA9763	1.2	0.92	9.4	1.6	2.1	8.6	3.0	2.2
35	JA9784	0.51	1.2	6.2	0.82	1.4	4.7	1.5	1.6
58	JA9793	5.6	1.7	45	1.2	4.5	17	5.3	9.0
40	JA9749	0.92	1.3	15	14	4.0	14	4.5	5.0
1	KT9989	5.6	1.0	28	2.2	2.8	9.8	3.6	5.4
38	JA9786	2.1	0.94	4.6	1.5	0.86	2.7	0.74	2.0

#	PSD	1,1,1-Trichloro ethane	Carbon Tetra chloride	Toluene	Tetrachlor oethylene	Ethyl benzene	(*m+p*) xylene	*o*-xylene	1,2,4-Trimethyl benzene
[illegible]									
89	TC3436	1.3	1.5	56	1.1	12	45	15	4.8
83	JC7947	3.0	1.1	11	0.25	2.9	9.3	2.9	3.6
66	JP1831	2.1	0.78	22	0.62	4.3	18	6.0	5.7
138	TK6427	4.3	1.4	10	0.80	1.7	6.2	2.6	4.4
93	JP1859	1.4	1.2	13	0.19	0.85	4.1	1.7	1.5
91	JC7774	8.3	1.2	25	2.2	3.5	13	4.2	10
42	JA9688	6.0	1.0	18	0.87	2.3	7.0	2.2	2.2
23	JA9617	5.0	0.81	10	2.6	3.3	11	4.2	14
120	JP2274	0.73	0.70	5.2	10	0.88	2.4	0.62	1.5
56	JA9818	0.99	0.98	2.9	0.25	0.80	3.5	1.0	1.7
7	TC0081	4.4	0.18	13	40	3.1	10	3.0	5.2
116	JP2522	1.5	0.84	29	0.40	20	78	22	18
106	JD2608	2.3	0.66	6.2	0.59	5.8	22	5.7	6.9
68	JA9707	0.39	0.59	8.4	0.25	1.7	4.8	2.7	4.8
60	JA9801	0.40	0.93	39	4.6	6.8	27	9.3	11
70	JA9810	0.28	0.60	3.5	0.26	2.3	7.8	3.9	29
142	KU7940	1.7	1.1	40	1.1	9.0	30	10	9.0
137	TK5905	0.50	1.1	12	0.26	3.6	13	4.8	4.6
6	TC0051	1.2	1.4	14	0.99	2.5	9.0	3.4	6.0
51	JA8875	0.58	0.95	3.2	0.68	0.41	1.9	0.48	1.2
130	TK5860	0.51	1.0	11	1.9	2.0	8.6	3.2	3.7
49	JA9849	0.41	0.72	0.10	0.26	0.58	1.7	0.60	1.3
135	TK5919	0.51	1.1	19	0.90	4.1	15	5.7	4.9
30	JA9812	0.47	1.1	0.51	0.48	0.27	1.1	0.30	0.95
86	TC3433	1.6	0.96	22	2.9	5.4	19	6.5	10
128	TK5987	0.47	1.1	17	1.8	2.8	11	3.6	5.0
4	TC0083	1.2	1.3	18	1.2	1.7	6.4	2.4	5.0
45	JA9622	0.68	0.97	0.10	0.26	0.36	1.2	0.46	1.0
148	TK5887	0.23	0.69	1.5	0.26	0.33	1.1	0.32	1.2
53	JP2133	0.67	0.78	82	0.26	0.49	1.7	0.32	1.8
104	JP2530	0.73	0.84	5.0	0.26	0.83	3.3	1.0	1.6
77	JC7873	0.72	1.1	0.10	0.26	0.10	0.91	0.40	1.2
14	TC0079	0.95	1.0	21	1.2	2.3	8.5	3.3	5.3
18	KT9961	0.84	0.98	12	1.2	1.8	6.4	2.4	4.7
73	JC7924	0.40	0.57	0.10	0.26	0.41	0.18	0.44	1.1
88	JD2609	0.51	1.1	4.2	1.9	2.0	7.6	2.7	2.8
47	JA9815	1.0	1.5	3.4	0.62	0.97	3.1	0.84	1.1
102	JP2169	0.72	1.2	8.5	0.26	1.1	4.2	1.6	1.7
100	JD2508	0.19	0.72	0.10	0.27	0.29	1.9	0.97	1.0
113	JD2488	0.37	0.94	0.10	0.26	0.20	0.42	0.11	0.90
80	JP2668	0.58	1.1	11	0.42	4.4	14	5.3	5.2
124	JP1782	1.2	1.3	4.9	0.26	0.82	3.1	1.5	1.6
26	JA9682	0.76	1.3	2.2	0.53	0.22	0.50	0.12	0.93
55	JA9807	0.26	0.19	0.10	0.26	0.10	0.12	0.16	0.59
115	JP2497	0.58	0.45	0.10	0.26	0.58	1.8	0.48	0.90
82	JD2541	0.47	0.98	2.0	1.2	1.6	5.3	2.1	2.1
22	JA9700	0.72	0.86	1.6	0.26	0.41	1.5	0.52	1.1
109	JD2552	0.44	1.1	0.10	0.23	0.37	1.5	0.27	0.87

#	PSD	1,1,1-Trichloro ethane	Carbon Tetra chloride	Toluene	Tetrachlor oethylene	Ethyl benzene	(*m*+*p*) xylene	*o*-xylene	1,2,4-Trimethyl benzene
[illegible]									
119	JP1904	0.83	1.0	2.9	0.49	1.1	3.7	0.93	1.7
10	KT9988	1.3	1.5	21	2.0	3.3	13	4.6	7.2
12	TC0043	0.59	1.0	15	0.82	3.0	11	4.0	6.1
63	JP2251	0.26	0.19	0.10	0.26	0.08	0.42	0.44	1.1
98	JD2621	0.28	0.78	0.10	0.03	0.08	0.63	0.23	0.71
132	JP1851	1.1	1.5	1.7	0.68	1.3	4.0	1.8	1.9
32	JA9722	3.0	1.1	14	7.5	3.4	12	4.4	25
34	JA9665	0.75	1.1	6.0	0.78	1.0	3.1	1.2	1.7
36	JA9613	0.34	0.7	0.10	0.26	0.27	1.8	0.33	1.4
59	JA9794	0.96	1.1	3.7	0.71	0.99	3.9	1.5	1.7
41	JA9663	0.73	1.1	0.10	0.40	0.69	2.4	0.59	1.1
2	KT9958	0.95	0.86	21	0.99	2.0	7.0	2.6	4.8
39	JA9732	0.68	1.1	0.10	0.37	0.31	1.6	0.47	0.90
90	KB9938	0.64	1.2	1.7	1.1	1.2	3.5	1.5	2.0
84	JC7897	0.50	1.0	0.10	0.26	0.65	2.6	1.1	1.8
67	JP1864	0.12	0.19	0.10	0.26	0.10	0.12	0.16	0.52
139	KU6353	0.82	1.5	7.8	2.0	0.74	1.4	0.68	1.8
96	JP2496	0.44	0.72	0.10	0.26	0.10	0.34	0.23	0.95
92	JP2281	0.40	0.87	0.10	0.19	0.12	0.12	0.11	0.91
43	JA9662	0.57	1.0	1.3	0.42	0.55	1.5	0.57	1.3
24	JA9775	0.42	1.1	6.7	2.3	0.28	2.6	0.76	1.2
121	JP2199	0.44	0.18	0.10	0.26	0.70	2.3	0.65	1.3
57	JA9800	0.31	0.82	2.2	0.26	0.08	0.79	0.36	0.79
8	TC0050	0.93	1.2	16	0.93	1.9	6.6	2.3	4.6
117	JP2233	0.57	0.71	0.10	0.19	0.82	2.7	0.64	1.3
107	JD2645	0.40	0.72	0.10	0.56	0.45	1.4	0.15	0.55
61	JA9868	0.19	0.72	0.10	0.26	0.10	0.12	0.16	0.47
71	JA9625	0.40	1.1	0.10	0.26	0.10	0.59	0.16	0.79
143	KT9960	1.2	1.4	1.8	0.26	0.10	0.01	0.72	2.8

8.11 Winter Results

Time Weighted Average Concentrations ($\mu g/m^3$)

#	PSD	1,1,1-Trichloroethane	Carbon Tetrachloride	Benzene	Tetrachloroethylene	Ethyl benzene	*(m+p) xylene*	*o*-xylene	1,3,5-Trimethyl benzene	1,2,4-Trimethyl benzene
156	TK6345	5.3	0.99	3.3	3.8	2.6	11	3.1	0.55	1.7
150	TK6242	1.3	1.2	5.4	0.25	3.2	12	2.9	0.48	2.5
264	TC3464	2.4	0.66	2.2	0.26	1.2	2.4	1.1	0.36	Missing
154	JP1756	2.2	0.84	3.9	2.1	1.7	7.3	2.7	1.3	4.8
204	TC3654	55	0.81	3.3	21	1.5	5.8	1.7	0.66	2.5
285	TC3378	0.39	0.70	0.81	0.48	1.1	4.3	1.7	0.32	1.1
152	TK6396	0.09	0.88	5.6	0.84	1.9	7.9	2.5	0.74	2.2
181	TC3669	1.1	1.0	5.3	2.3	3.2	13	4.8	2.7	9.9
271	TC3381	1.7	0.60	1.5	0.78	1.3	6.7	2.4	0.63	2.8
229	TC3970	16	1.1	5.5	1.7	3.3	11	4.2	1.4	4.4
279	TC3351	0.94	0.77	1.7	0.19	1.8	7.4	1.9	0.36	0.89
251	KT9899	1.3	0.77	1.9	0.63	0.84	2.8	1.8	0.62	2.0
206	TC3651	37	2.2	4.6	0.66	35	140	45	1.9	5.7
158	TU2567	50	0.88	2.3	0.37	5.6	24	9.3	3.6	13.5
200	TU2609	3.1	0.68	1.2	1.9	1.1	3.3	1.7	0.24	0.58
208	TC3524	1.0	0.88	1.2	0.30	0.76	3.1	1.1	0.59	1.8
235	TC0208	0.56	0.73	3.6	3.0	1.7	8.1	3.1	0.96	2.7
212	TC3514	1.0	1.9	0.63	5.7	3.0	8.4	4.4	1.5	5.3
202	TC3486	0.67	1.1	3.4	0.05	3.9	18	5.8	1.4	6.0
210	TC3517	19	2.2	12	4.2	14	57	27	4.8	18
233	TC0205	0.26	0.88	5.8	0.62	2.1	6.8	2.6	0.81	2.6
245	KT9896	0.23	1.0	4.3	8.5	1.7	7.1	3.1	1.2	4.6
243	KT9900	3.3	1.3	1.8	0.52	0.96	3.3	1.6	2.1	8.4
249	KT9891	0.73	0.84	1.5	0.25	0.96	3.2	1.8	2.1	7.4
225	TC3642	3.0	1.9	3.4	6.1	2.2	7.4	4.0	1.8	5.9
179	TC3664	0.39	0.84	4.4	0.70	1.68	6.0	2.0	0.47	1.8
261	KT9980	0.40	0.18	1.3	1.4	0.40	1.9	1.4	0.36	1.7
283	TC4054	0.84	0.70	3.5	1.8	2.6	11	3.0	0.70	3.2
273	TC3377	0.64	0.56	1.9	0.34	1.6	6.4	10	25	89
227	TC3957	0.70	0.88	3.8	1.6	2.0	8.4	3.6	1.0	3.8
241	TC0207	19	0.70	6.2	4.7	1.6	6.7	3.0	0.74	2.6
171	TC3478	1.9	0.48	7.8	0.52	3.0	12	3.2	0.62	2.7
177	TC3658	12	0.85	3.9	0.99	2.1	5.8	1.5	0.32	1.3
216	TC3527	7.8	0.68	4.5	3.6	6.1	24	7.7	1.4	6.7
175	TC3657	7.8	0.18	2.4	0.59	0.76	2.4	0.53	0.20	0.73
188	TC3398	0.50	0.99	1.7	0.25	1.3	4.8	1.7	0.62	2.3
198	TC3391	7.8	1.1	11	2.5	3.7	14	4.9	0.75	3.4
163	TK6096	0.63	0.99	3.9	0.99	1.0	4.7	1.3	0.01	0.10
257	TC3971	0.33	0.55	0.79	0.64	0.28	1.6	1.1	0.55	1.8

219	TC3473	2.4	1.7	2.4	0.19	2.1	8.9	4.1	1.1	4.5

#	**PSD**	**1,1,1-Trichloroethane**	**Carbon Tetrachloride**	**Benzene**	**Tetrachloroethylene**	**Ethyl benzene**	***(m+p) xylene***	***o*-xylene**	**1,3,5-Trimethyl benzene**	**1,2,4-Trimethyl benzene**
[redacted]										
196	TC3396	0.18	0.69	0.63	0.23	0.10	0.03	0.05	0.05	0.04
185	JP1730	0.97	0.81	4.5	0.23	6.6	25	6.3	0.97	4.6
223	TC3644	0.97	1.8	5.3	290	2.6	6.4	3.4	1.3	5.5
292	TC3485	4.0	0.48	0.63	2.1	1.3	5.1	1.7	0.90	3.7
277	TC3385	0.46	0.77	0.63	0.48	0.11	0.12	1.6	0.05	0.58
287	TC4066	0.77	1.0	5.2	0.81	4.3	17	3.3	0.63	2.1
183	TK6076	0.94	0.88	5.2	0.25	1.6	7.6	2.5	0.24	1.2
165	TC3490	1.7	0.81	3.7	1.1	1.5	7.2	2.4	0.74	2.8
167	TC3487	5.1	0.89	3.7	0.28	1.3	5.3	1.9	0.51	2.1
160	TC3663	1.5	1.2	3.9	0.95	0.59	2.1	0.76	0.47	1.7
173	TC3471	13	0.18	2.7	0.16	1.4	6.7	2.5	0.78	2.4
259	KT9982	3.4	0.18	2.4	0.25	0.64	2.4	0.38	0.09	0.16
255	KT9987	2.7	0.62	1.4	1.2	0.98	3.1	1.9	0.76	3.0
194	TC3375	1.8	0.98	1.8	4.1	2.1	6.9	2.8	0.66	2.2
299	TC3357	0.46	0.74	1.6	0.25	0.93	2.9	1.1	0.01	0.47
253	TC3961	0.98	0.70	1.5	0.74	0.72	3.2	2.1	0.47	2.2
239	TC0200	1.8	0.88	1.3	3.6	0.48	2.3	1.1	0.32	1.3
289	TC4047	1.0	0.66	3.1	1.5	1.6	6.8	1.4	0.63	2.6
192	TC3384	0.94	1.6	4.3	0.25	2.1	7.1	2.9	1.2	5.8
214	TC3533	1.1	2.2	18	0.69	11	45	22	5.3	19
237	TC0202	0.43	1.6	2.2	0.70	1.6	5.6	2.5	1.1	4.2
275	TC4061	0.26	0.96	0.69	0.38	0.64	2.3	2.1	5.2	17
[redacted]										
157	TK6257	0.09	0.70	4.1	0.13	1.5	6.0	2.1	0.34	0.69
151	TK6102	0.22	0.92	3.6	0.27	1.3	5.7	2.5	0.34	1.2
265	TC3383	0.13	0.61	0.56	0.27	0.29	0.53	0.06	0.12	0.10
155	TK6248	0.20	0.89	4.7	0.27	0.42	3.8	1.4	0.05	0.10
205	TC3648	0.67	1.2	0.66	0.51	0.93	2.2	0.60	0.26	1.4
286	TC3374	0.05	0.53	0.84	0.26	0.49	2.5	0.92	0.09	0.28
153	TK6214	0.27	0.93	5.8	0.20	1.2	4.2	1.5	0.22	0.41
182	TC3666	0.48	0.91	5.3	2.1	3.4	14	5.1	1.4	4.5
272	KT9979	0.28	0.78	0.80	0.02	0.11	0.13	0.17	0.12	0.10
232	TC3963	0.34	0.19	3.1	0.54	1.9	7.0	3.1	0.93	3.0
282	TC3350	0.23	0.84	1.8	0.50	1.8	6.4	1.8	0.49	2.2
252	KT9894	0.48	0.92	1.4	0.26	0.03	0.70	0.55	0.37	0.72
207	TC3520	1.1	2.0	0.66	1.5	2.1	5.2	2.4	0.86	4.0
159	JP1889	0.17	1.0	3.4	0.27	0.85	3.2	1.1	0.09	0.01
201	TC3461	0.20	0.89	1.2	0.27	0.46	0.83	0.93	0.25	0.37
209	TC3530	0.63	1.0	0.53	0.35	0.50	1.5	0.68	0.29	1.0
236	TC0204	0.63	0.77	2.6	0.20	1.4	6.8	3.0	0.89	3.0
213	TC3511	0.55	1.4	0.14	0.42	0.45	0.13	0.67	0.25	1.1
203	TC3484	0.20	0.97	0.66	0.01	0.16	0.41	0.56	0.13	0.09
211	TC3508	0.70	2.5	0.66	0.47	5.3	0.08	0.17	0.89	3.3
234	TC0209	0.27	0.76	2.6	0.31	1.2	6.1	2.5	0.64	2.1

246	KT9902	1.0	0.77	4.8	0.88	2.0	8.7	4.0	1.1	4.7
244	KT9901	0.34	0.57	2.4	0.28	0.83	3.7	1.7	0.41	1.6
#	**PSD**	**1,1,1-Trichloro ethane**	**Carbon Tetra chloride**	**Benzene**	**Tetrachlor oethylene**	**Ethyl benzene**	***(m+p) xylene***	**o-xylene**	**1,3,5-Trimethyl benzene**	**1,2,4-Trimethyl benzene**
[redacted]										
250	KT9895	0.34	0.80	1.8	0.46	0.16	0.45	0.42	0.29	0.48
226	TC3641	0.78	1.8	3.0	1.6	2.5	6.8	3.3	1.2	4.0
180	TC3660	0.30	0.79	4.2	1.4	1.6	6.2	2.0	0.48	1.9
262	KT9981	0.27	0.73	0.65	0.24	0.10	0.32	0.06	0.01	0.10
284	TC4057	0.56	0.81	0.75	0.26	1.3	4.8	1.3	0.29	1.1
274	TC3380	0.20	0.63	0.63	0.27	0.11	0.13	0.17	0.12	0.10
228	TC3960	2.2	0.19	0.66	0.26	5.39	0.41	0.17	0.53	1.6
[redacted]										
242	TC0206	0.16	0.69	1.5	0.26	0.20	1.1	0.88	0.25	1.1
172	TC3481	0.20	0.72	3.0	0.39	0.03	0.57	0.22	0.09	0.48
178	TC3661	0.51	0.80	2.3	0.54	0.49	2.4	0.55	0.29	0.95
217	TC3387	1.0	1.6	1.6	0.20	1.2	4.2	1.8	0.72	2.9
176	TC3667	0.30	0.87	2.1	1.4	0.70	2.8	0.79	0.33	1.19
189	TC3388	0.16	0.81	1.0	0.27	0.46	1.2	0.93	0.25	0.88
199	TC3460	0.43	1.2	2.9	0.12	0.62	2.0	0.63	0.29	0.88
164	TK6233	0.09	0.86	3.4	0.13	0.16	2.5	0.86	0.05	0.10
258	TC3968	0.30	0.84	0.55	0.26	0.16	1.2	0.18	0.01	0.10
220	TC3470	0.31	1.1	1.8	0.36	0.33	1.8	0.81	0.62	1.7
197	TC3397	0.56	1.1	0.66	0.05	0.54	0.95	0.43	0.17	0.65
186	JP1901	0.48	0.76	2.4	0.26	0.53	3.0	1.1	0.01	0.10
224	TC3647	1.4	7.2	0.34	1.5	0.58	5.4	3.2	0.86	3.4
293	TC3488	0.09	0.61	0.66	0.26	0.11	0.41	0.26	0.12	0.10
278	TC3382	0.09	0.68	0.27	0.27	0.32	0.16	0.01	0.12	0.10
288	TC4060	0.31	0.79	0.66	0.33	1.1	5.0	1.1	0.21	0.68
184	TK5906	0.12	0.61	3.6	0.01	0.16	2.1	0.63	0.12	0.10
166	TC3483	0.23	0.53	1.7	0.09	0.28	0.94	0.51	0.12	0.28
170	TC3477	0.55	1.1	2.8	0.46	0.49	1.4	0.51	0.17	0.56
162	TK5869	0.09	0.85	2.5	0.27	0.11	0.66	0.17	0.12	0.10
174	TC3474	0.34	0.95	3.4	0.42	0.12	0.78	0.22	0.05	0.32
260	TC3958	0.24	0.73	0.79	0.26	0.04	0.12	0.17	0.12	0.10
256	KT9985	0.27	0.69	0.75	0.01	0.10	0.12	0.17	0.12	0.10
300	TC3355	0.13	0.58	0.65	0.26	0.12	0.49	0.14	0.12	0.10
195	TC3379	0.13	0.46	0.04	0.27	0.11	0.28	0.10	0.12	0.10
254	TC3964	0.30	0.31	0.81	0.80	0.08	0.12	0.59	0.21	1.0
240	TC0201	0.23	0.65	1.4	0.28	0.33	0.45	0.30	0.13	0.40
290	TC4048	0.38	0.65	0.78	0.09	0.50	1.7	0.55	0.01	0.09
193	TC3376	0.30	0.69	0.66	0.27	0.11	0.13	0.17	0.12	0.10
215	TC3521	1.1	1.83	6.69	0.57	4.5	0.20	0.17	0.80	2.7
238	TC0203	0.41	0.73	1.0	0.50	0.12	0.53	0.35	0.21	0.61
276	TC3373	0.34	0.78	0.40	0.27	0.11	0.13	0.18	0.12	0.10